US Army Corps
of Engineers
Buffalo District

Blanchard River Watershed Study
Interim Feasibility Report

Appendix A:
Hydrology and Hydraulics

April 2015

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EXECUTIVE SUMMARY

The city of Findlay, OH has experienced frequent flooding from the Blanchard River and its tributaries. From its headwaters, the Blanchard River flows north and turns to the west just before entering the city of Findlay. Tributaries Lye Creek and Eagle Creek also flow north, emptying into the Blanchard River at Findlay. The hydrology, hydraulics, and the interactions between these three waterbodies were considered in defining and evaluating an effective flood risk management project for this area.

A coupled hydrologic and hydraulic (H&H) model was developed to assess baseline conditions and to evaluate alternative flood risk management controls. A hydrologic model was developed to simulate flows throughout the watershed for storm events at a variety of frequencies of occurrence. A steady flow hydraulics model was developed to simulate peak water surface elevations along the Blanchard River and its tributaries, and to define peak flood inundation areas. The two models were coupled by using the peak flow outputs, from the hydrologic model simulations, as flow changes at various stations along the Blanchard River and tributary reaches in the hydraulic model.

The hydrologic model was calibrated against observed hydrographs for the October 2011 high flow event, validated for the September 2011 flow event, and verified for the February 2008 and August 2007 high flow events. The hydraulic model was calibrated against observed high water marks for the August 2007 flood event. Model calibrations and validations show a good fit between simulated and observed hydrographs.

The coupled H&H model was used to establish baseline conditions, thus evaluating the "no-action" alternative (Alternative 1). The hydraulic model was then modified to reflect four additional flood risk management alternatives (Alternatives 2 – 5). All four alternatives include a diversion channel diverting flow from Eagle Creek to the Blanchard River, downstream of Findlay. In each case the diversion channel is in the same location but with conveyance needed for the 2% annual chance (50-year) event, 1% annual chance (100-year) event, or 0.4% annual chance (250-year) event flood. Three of the alternatives also include a levee cutting off flow between the Blanchard River and Lye Creek, upstream of Findlay.

Water surface profiles were calculated for the 50% annual chance (2-year) event, 20% annual chance (5-year) event, 10% annual chance (10-year), 4% annual chance (25-year), 2% annual chance (50-year), 1% annual chance (100-year), 0.5% annual chance (200-year), and 0.2% annual chance (500-year) flood events for each of the alternatives. Results from the alternatives model simulations are presented as reductions in peak flood water surface elevations. Flood water surface elevations are provided for use in a subsequent alternatives cost/benefit analysis.

1. INTRODUCTION

A flood risk management project is being developed for the city of Findlay, in the Blanchard River Watershed, in northwestern Ohio. The Blanchard River flows from its headwaters in Kenton, Ohio north to bend west around Findlay, Ohio continuing west to Ottawa, Ohio and finally emptying into the Maumee River.

Four of the top nine floods of record have occurred in Findlay since 2007 causing tens of millions of dollars in damages. Frequent flooding has impacted the quality of life in the watershed.

This hydrology and hydraulics study provides an assessment of the effectiveness of various flood risk management alternatives in reducing peak water surface elevations.

2. ANALYSIS METHODOLOGY

A coupled watershed hydrology and stream hydraulics model was developed to assess the effectiveness of various alternative plans and to inform the recommendation of a Tentatively Selected Plan (TSP). This includes discussions of the previous modeling efforts and how it was incorporated into the current analysis, the process for creating the new H&H model.

The hydrologic model was developed utilizing the Hydrologic Modeling System (HMS) software developed by Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE). The development of the Blanchard Watershed HEC-HMS model included pre-processing of available Geographic Information System (GIS) data using the HEC-GeoHMS toolset in ArcGIS. The hydraulic modeling analysis was performed using the HEC River Analysis System (RAS v. 4.1.0) hydraulic model in steady state mode. The hydraulic model update, mapping of the flooding extent also determined by HEC-GeoRAS, an ArcGIS based tool from the HEC.

The purpose of the hydrologic model was to quantify the runoff from the Blanchard River watershed under various extreme flood conditions. These runoff rates were then used in evaluating the hydraulic performance of the various flood risk management alternatives considered for the City of Findlay and vicinity.

A new HEC-HMS model was developed using the HEC-GeoHMS v10.2 extension toolset in ArcGIS v10.2. HEC-GeoHMS utilizes available GIS data to delineate subbasins, determine reach hydrologic routing characteristics and develop initial estimates of parameters. Once initial parameters were established for the hydrologic model, water level and flow data from historic storm events were used to calibrate the model parameters.

The purpose of the hydraulic model was to simulate the water surface elevations corresponding to peak flood flows along the Blanchard River and its tributaries. No new hydraulic model was created in this analysis. The previously developed Buffalo District Blanchard River HEC-RAS model was updated where necessary to reflect current topography using the HEC-GeoRAS v10.2 extension toolset in the ArcGIS v10.2. The HEC-RAS model was further enhanced by calibrating against the 2007 flood high water marks surveyed by the Federal Emergency Management Agency (FEMA). The HEC-GeoRAS tool was also used to define the alternative proposed plans for analysis in the HEC-RAS software.

The HEC-HMS model was used to develop hypothetical storm flow responses for each subbasin and route flows through the Blanchard River watershed. The HEC-RAS model was used to develop the water-surface-elevation/flow relationship for the channel routing method and to predict water surface elevations for a given discharge. The coupling of hydrologic & hydraulic (H&H) models involved simulations of peak flows at key locations along the Blanchard River and tributaries in HEC-HMS then using these peak flows as flow change locations in the steady-state HEC-RAS model. The key locations are primarily at confluences along the river or locations of diversion.

3. HYDROLOGIC MODELING OF BLANCHARD RIVER

3.1. Introduction

3.1.1 Project Purpose

The city of Findlay, Hancock County, Ohio, has experienced frequent flooding from the Blanchard River. The purpose of this study was to develop a rainfall-runoff model of the Blanchard River basin using the HEC-HMS model. The model was developed using HEC-GeoHMS and available GIS datasets and then calibrated and validated to historic flood events using NEXRAD precipitation data. The validated model was used to estimate frequency flows for use with the HEC-RAS river hydraulics model to evaluate existing conditions and alternative flood damage reduction measures.

3.1.2 Watershed Description

The Blanchard River Watershed is located in portions of Allen, Hancock, Hardin, Putnam, Seneca and Wyandot Counties in northwest Ohio, as shown in Figure 1.

The headwaters are located in Hardin County where the river flows northerly until just east of the city of Findlay. The Blanchard River then turns westwards until the confluence with the Auglaize River near the village of Dupont in Putnam County. Two major tributaries of Blanchard River are Lye Creek and Eagle Creek. Both creeks join Blanchard River within the Findlay city limits. The total drainage area of the Blanchard River watershed is 809 square miles and the total river length is 84.9 miles.

Over 80% of the watershed is cropland, and over 83% of the watershed has a slope of two percent or less. The largest city in the watershed is Findlay. The total population in the Blanchard River Watershed is estimated to be 91,266 (NRCS, 2008).

Portions of six counties are found within the watershed, ranging from Hancock County (71.0%) to Seneca County (1.6%). Cities and villages that are situated entirely or partly in the Blanchard River Watershed include the communities of Arlington, Beaverdam, Benton Ridge, Bluffton, Columbus Grove, Continental, Dunkirk, Dupont, Findlay, Forest, Gilboa, Glandorf, Jenera, Kenton, Miller City, Mount Blanchard, Mount Cory, Ottawa, Pandora, Patterson, Rawson, Vanlue and Wharton.

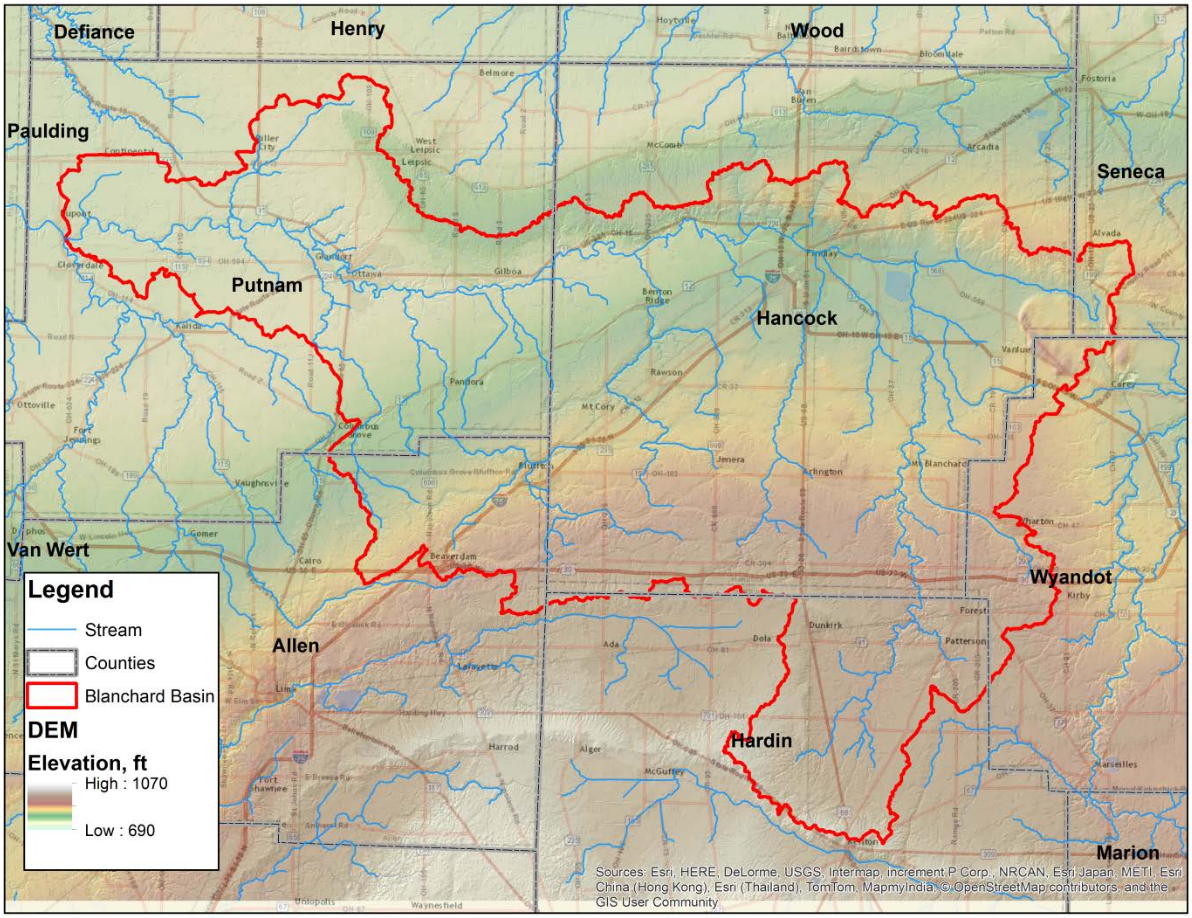

Figure 1. Location of the Study Area

3.2 Modeling Data

3.2.1 GIS Terrain Data and Layers

Several types of GIS data layers were used to develop the hydrologic model of the study area. The data, source, and description are summarized in the Table 1.

Table 1. Summary of GIS data Used in Developing HEC-HMS Model

Data	Description and Source
DEM	10m Digital Elevation Model (DEM) data was used for development of the hydrologic model for this study. Source: http://seamless.usgs.gov
Imagery	Aerial photographs were used to determine Manning's n surface roughness values. Source: http://seamless.usgs.gov
DRGs	Digital Raster Graphics (scanned quad sheets) were used for background referencing of terrain elevations and location names. Source: http://seamless.usgs.gov
Land use	The Multi-Resolution Land Characteristics Consortium (MRLC) maintains a land cover database for the entire nation. This dataset was used to inform the Soil Conservation Service (SCS) Curve Number (CN) estimate for each subbasin in the study area. Source: http://www.mrlc.gov
Soils	Polygon soils data were used to inform the SCS Curve Number estimate for each subbasin in the study area. Source: NRCS SSURGO database, http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/

The topography and land use of the study area are shown in Figure 1 and Figure 2, respectively. The higher elevations of the watershed are characterized largely by cultivated lands with some forest and pasture/hay; whereas the lower portions of the watershed are more urban.

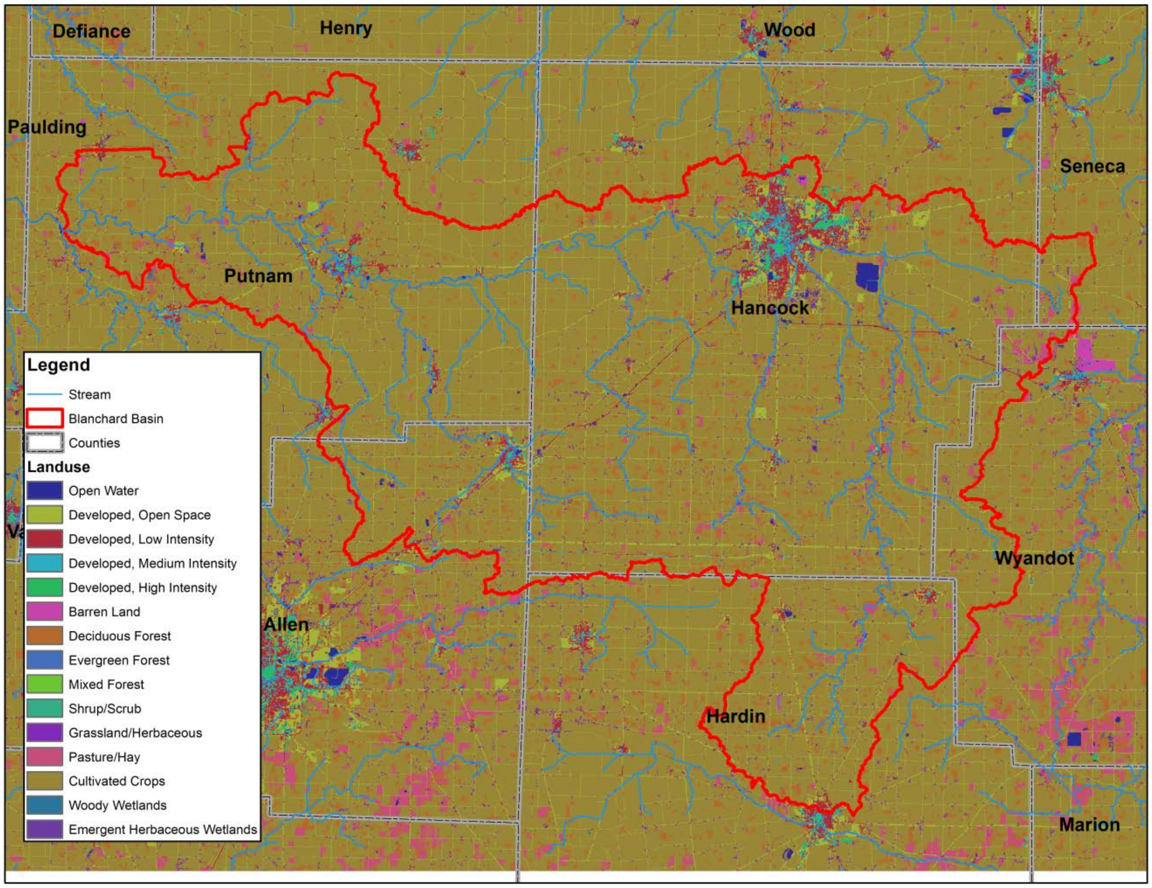

Figure 2. Land Use in the Study Area

The Soil Survey Geographic (SSURGO) database developed by the Natural Resources Conservation Service (NRCS) was used in developing the model for the Blanchard River watershed. The SSURGO soil survey data includes a GIS layer of soil types and a database with information associated with each soil type. The database groups all soils into one of four Soil Conservation Service (SCS) Hydrologic Soil Groups (HSG): A, B, C, and D. Figure 3 shows a portion of the SSURGO data in the area of Blanchard Falls. Each polygon in Figure 3 represents a different soil type, with an associated HSG, within the SSURGO database.

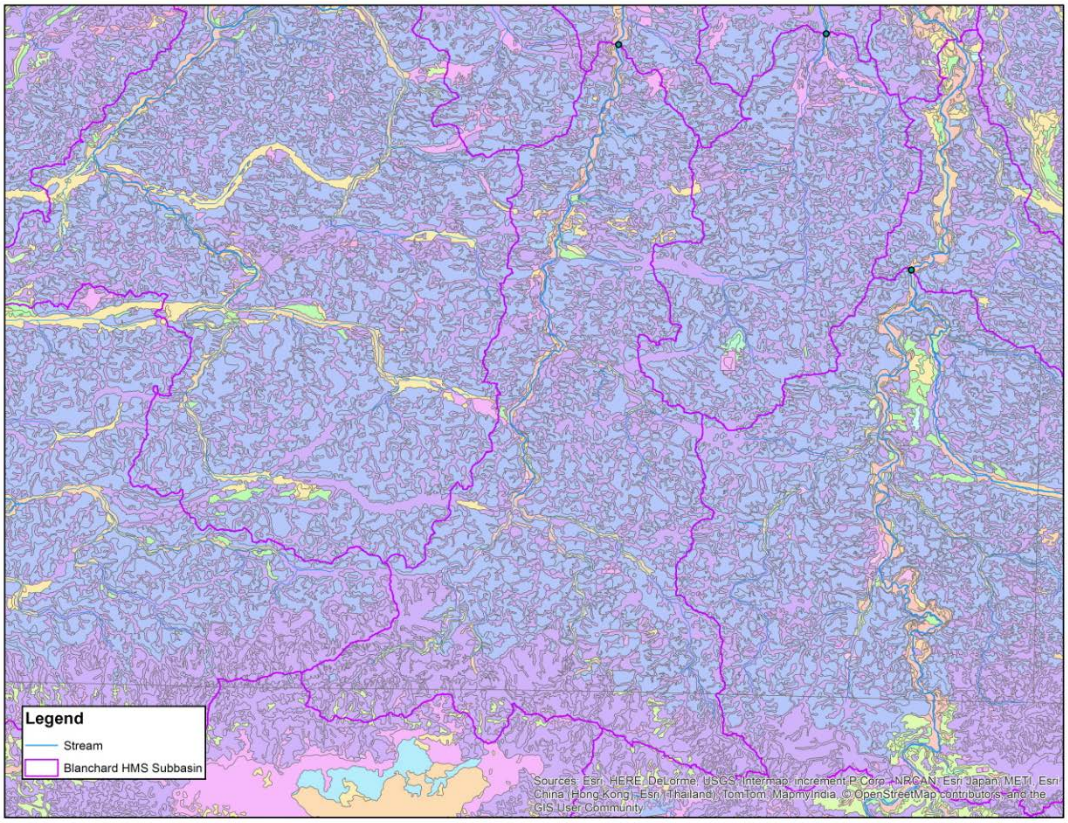

Figure 3. SSURGO Soil Survey Data in the Vicinity of Eagle Creek Basin

3.2.2 Rainfall Data

For this study, model calibration and validation was accomplished using Next-Generation Radar (NEXRAD) Stage III radar-rainfall data. Data for all of the events were collected from the National Weather Service (NWS). These radar data were acquired as hourly values stored in XMRG format on the Hydrologic Rainfall Analysis Project (HRAP) coordinate system. The GridLoadXMRG program was used to convert the data from XMRG format to gridded records in a HEC Data Storage System (DSS) database for reading by HMS during simulation runs.

The 0.2%, 0.4%, 1%, 2%, 4%, 10%, 20% and 50% annual exceedance probability (500-yr, 250-yr, 100-yr, 50-year, 25-year, 10-year, 5-year and 2-year return period) rainfall frequency events were analyzed in this study and were defined in the HEC-HMS model for the Blanchard River watershed. The total rainfall depths (in inches) for each annual chance storm were collected from the NOAA Atlas 14, Volume 2 (http://dipper.nws.noaa.gov/hdsc/pfds/) and are shown in Table 2. The SCS 24-hour Type II rainfall distribution, typical for most of the continental U.S., and appropriate for the study area, was used.

Table 2. Frequency Precipitation Depth in the Study Area

Frequency	Precipitation (inches)
0.2% Annual Chance (500-year)	6.69
0.4% Annual Chance (250-year)	5.98
1% Annual Chance (100-year)	5.24
2% Annual Chance (50-year)	4.67
4% Annual Chance (25-year)	4.13
10% Annual Chance (10-year)	3.47
20% Annual Chance (5-year)	3.00
50% Annual Chance (2-year)	2.44

3.2.3 Streamflow Data

15-min and 1-hour stream flow data were downloaded from the United States Geological Survey (USGS) Instantaneous Data Archive System (http://ida.water.usgs.gov/ida/) for USGS stations within the Blanchard River watershed. USGS gage names, station IDs, drainage areas, and latitude and longitude coordinates are contained in Table 3 and gage locations are shown in Figure 4. All downloaded data was imported into a HEC-DSS file using HEC-DSSVue.

Table 3. USGS Streamflow Gages for the Blanchard River Watershed

Gage Name	Station ID	Drainage Area (mi^2)	Longitude	Latitude
Blanchard River at Findlay OH	04202000	346	83°41'17"	41°03'21"
Blanchard River at Ottawa OH	04189260	628	84°02'49"	41°01'01"
Riley Creek below Pandora OH	04189174	70.3	83°58'35"	40°58'23"
Eagle Creek above Findlay OH	04188496	51.0	83°39'12"	40°58'45"
Lye Creek above Findlay OH	04188433	18.8	83°35'09"	40°58'57"
Blanchard River above Findlay OH	04188400	233	83°34'46"	41°02'02"
Blanchard River below Mt. Blanchard OH	04188337	141	83°33'26”	40°55'28"

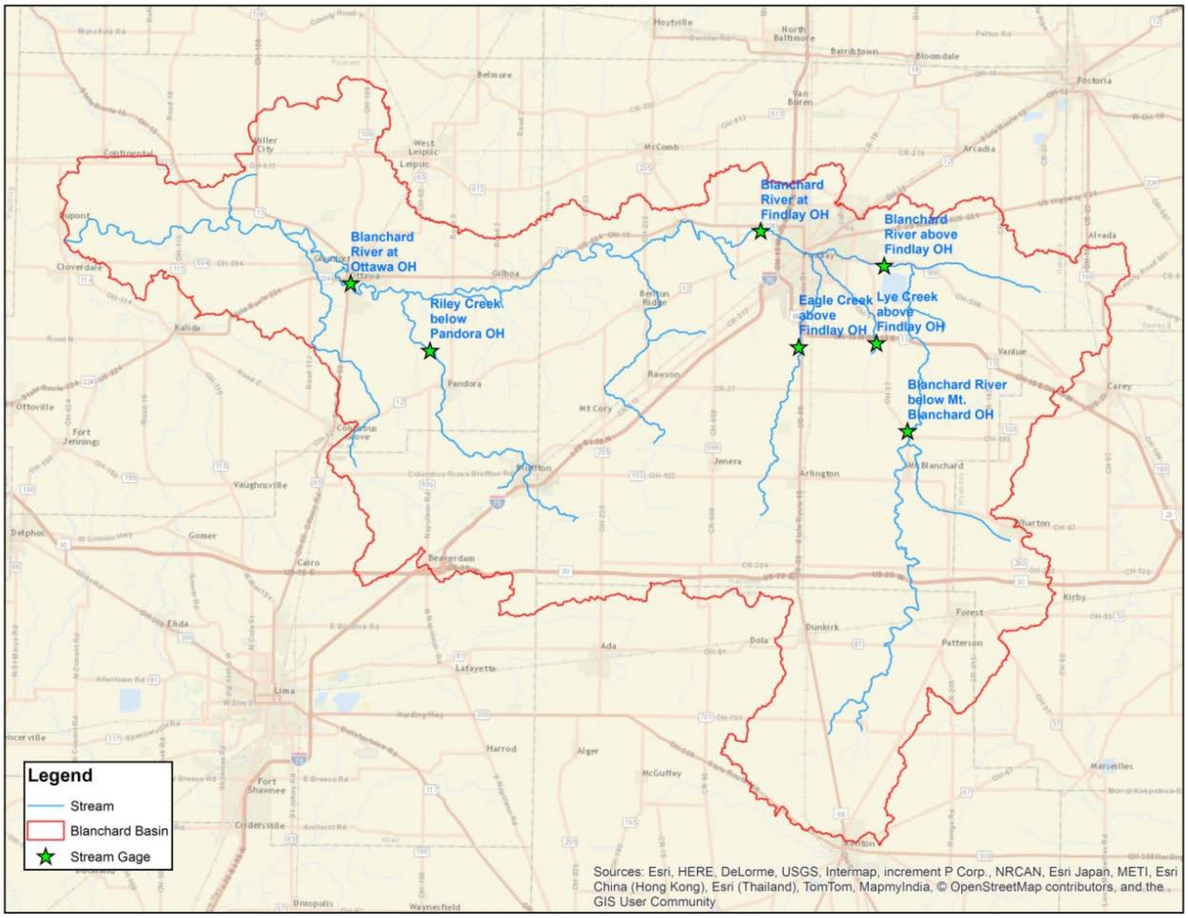

Figure 4. Location of Streamflow Gages Used in the Blanchard River Study

3.2.4 Cross-Section Data

Representative cross sections for routing reaches were defined as 8-point cross sections where cross-section data was available from the Buffalo District hydraulic model (HEC-RAS).

3.3 Hydrologic Model Development

3.3.1 Objective of the Model Development

The purpose of this study is to develop a calibrated hydrologic model using HEC-HMS v4.1 of the Blanchard River Watershed located in northwest Ohio as part of the Blanchard River Flood Risk Management (FRM) Feasibility Study (FS).

3.3.2 Development of the HEC-HMS Model

An HEC-HMS model has three main components: basin model, meteorological model, and control specifications. The basin model contains the physical description of the watershed. Hydrologic elements (subbasins, reaches, sources, sinks, reservoirs, and junctions) are connected to one another to define the physical representation of the real world watershed. The hydrologic elements also require parameter information, like loss rates, in order for the program to compute the rainfall-runoff response in the watershed. The meteorological model calculates the precipitation input needed by subbasin elements in the basin model. The control specification defines the time period and time step required for simulations.

HEC-HMS contains many methods for simulating the rainfall-runoff response in a watershed. These methods include simple approaches, like the SCS curve number method with only one parameter, to a more complex approach, like the 24 parameter soil moisture accounting method. The program also contains multiple methods for modeling the transformation of excess precipitation to direct runoff at the subbasin outlet, baseflow, and the movement of water from an upstream location to a downstream location (channel routing). A summary of the equations and required parameters for each method are included in the HEC-HMS Technical Reference Manual (HEC, 2000).

Table 4 contains modeling methods chosen for this study and a list of required parameters associated with each methodology.

Table 4. Blanchard River HEC-HMS Modeling Methods and Required Parameters

Modeling Method	Parameter	Description
SCS Curve Number	Initial Abstraction	Short-term surface storage and initial infiltration.
	Curve Number	An empirical parameter based on hydrologic soil group, land use, and hydrologic condition that is used for estimating direct runoff.
	Percent Impervious Area	Percent of the subbasin that is covered by impenetrable surfaces such as concrete, rooftops, and urban development.
Clark Unit Hydrograph Method	Time of Concentration	Travel time from the most hydrologically remote point in the subbasin to the watershed outlet.
	Storage Coefficient	Accounts for storage in the watershed.
Recession Baseflow	Recession Constant	Constant used to estimate shape of recession limb of the hydrograph.
Muskingum-Cunge Routing Method	Channel Length	Length of the channel reaches for routing.
	Slope	Slope of the channel reach.
	Channel Shape	Representative channel shape (8-point cross section).
	Manning's n values	Representative channel roughness.

The development of the HEC-HMS model began with HEC-GeoHMS. HEC-GeoHMS is a GIS tool that is a software extension to ArcGIS (HEC, 2013b). It allows the user to visualize spatial information, document watershed conditions, perform spatial analysis, and to help define the structure and parameter inputs of the hydrologic model. HEC-GeoHMS was used to process the DEM and delineate subbasin and river reaches in the Blanchard River watershed. HEC-GeoHMS was also used to estimate model parameters using GIS data.

Finally, HEC-GeoHMS created HEC-HMS specific files that contained the hydrologic connectivity of the Blanchard River watershed as well as hydrologic parameters. Once the files were imported into HEC-HMS, the model was further parameterized and calibrated to historic rainfall-runoff events. Model parameters were adjusted, within reasonable limits, until the model was able to reproduce, as accurately as possible, observed runoff hydrographs.

3.3.3 HMS Model Initial Parameter Estimation using GIS Data

A digital terrain model (DTM) was developed from the 10-foot DEM downloaded from USGS to perform subbasin and drainage network delineations using HEC-GeoHMS. In addition to the DTM, the National Hydrography Dataset (NHD), available from the USGS, was downloaded for the Blanchard River. The NHD contains water body and basin boundary feature datasets that are useful for defining the drainage network. The NHD data was downloaded from http://nhd.usgs.gov/index.html.

The DEM downloaded from the USGS was processed using ArcGIS tools before being used by HEC-GeoHMS to develop the hydrologic network. This included re-projecting the DEM from the geographic coordinate system to the Ohio State Plane North coordinate system and converting the vertical units from meters to feet. In addition, the surface water layer from NHD was "burned" into the DEM. The burning-in process lowers all grid cells that are located beneath a line in the NHD stream layer. This forces the NHD drainage pattern onto the DEM.

HEC-GeoHMS was used to process the DEM to define subbasin boundaries (HEC, 2009). Subbasin outlets (model junctions) were defined at all major stream gage locations, at the outlets of all major tributaries, and at points of interest. Subbasin delineations for the Blanchard River watershed are shown in Figure 5. Subbasin names and the associated drainage areas are summarized in Table 5.

GIS data layers for land uses and soils types were used to estimate the SCS curve numbers for each subbasin. Land use data was acquired from the Multi-Resolution Land Characteristics Consortium (MRLC) and the soil data was obtained from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database. One attribute contained in the SSURGO database is the Hydrologic Soil Group (HSG) associated with each polygon in the soil layer. Table 6 contains descriptions of the four hydrologic soil groups. The land use and SSURGO data layers were intersected with one another resulting in polygons with unique land use and hydrologic soil groups. Then a lookup table, Table 7, was use to relate each land use/soil group combination to a curve number (CN). Table 7 was developed using information in TR-55 (USDA, 1986). HEC-GeoHMS was used to compute the subbasin average CN contained in Table 8. These CNs were treated as initial estimates; these parameter values were adjusted during model calibration to improve results.

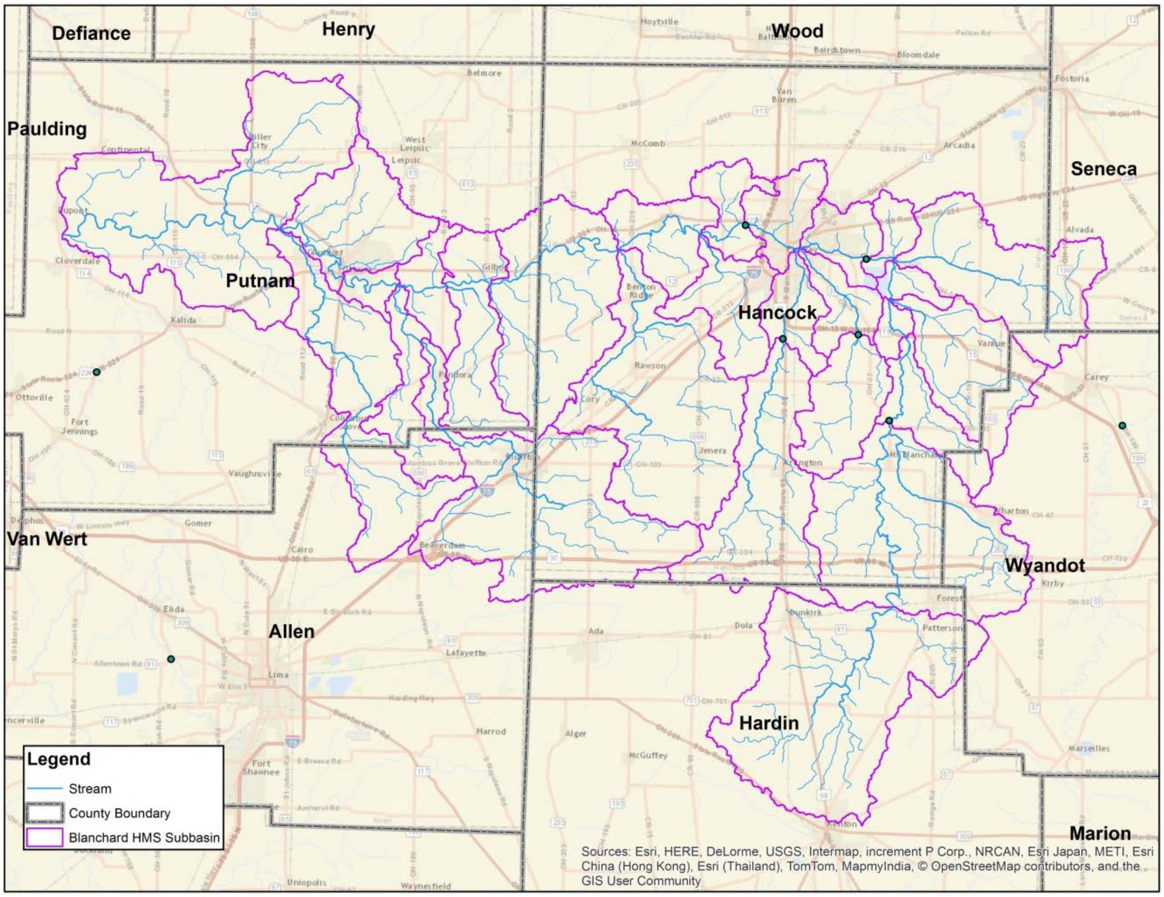

Figure 5. Subbasin Delineation for the Blanchard River HEC-HMS Model

The time of concentration, i.e. the time it takes for runoff to travel from the most distant point in the watershed to the outlet, was estimated using the TR-55 methodology (USDA, 1986). GIS was used to determine the distance direct runoff travels along the longest flow path as sheet flow, shallow concentrated flow, and channel flow. Physical parameters such as length and slope were computed using the GIS. Initial estimates were then modified as described in Section 3.3.4, below.

Table 5. Blanchard River HMS Subbasin Names and Drainage Areas

HMS Subbasin Name	Area (Square Miles)
W1090	65.104
W1100	77.451
W1150	13.938
W1140	3.3769
W550	27.982
W480	4.1821
W470	38.544
W890	5.6411
W730	9.7527
W880	9.8341
W740	19.502
W780	9.9525
W790	43.168
W940	11.653
W400	17.718
W930	9.6968
W580	63.512
W350	15.804
W410	48.706
W530	23.425
W520	9.9495
W990	15.593
W640	69.766
W1050	4.2263
W430	45.38
W1040	26.436
W370	83.725

Table 2. Description of Hydrologic Soil Groups

Hydrologic Soil Group	Characteristics
A	Deep, well drained coarse soils (gravel, sand, loamy sand, or sandy loam).
B	Moderately deep and well drained soils that are moderately coarse to moderately fine (silt loam or loam).
C	Moderately fine to fine soils (sandy clay loam).
D	Mainly clay soils or shallow soils over clay layers that impeded infiltration (clay loam, silty clay loam, sandy clay, silty clay, or clay).

3.3.4 Calibration of Subbasin Parameters

The Clark's unit hydrograph method was the method chosen to simulate the translation of net precipitation through the subbasin. As discussed previously, time of concentration (Tc) was computed using the TR-55 method. The Clark storage coefficient (R) is a calibration parameter that affects the shape of the runoff hydrograph, meaning this parameter must be set using measured rainfall-runoff data. Initial estimates for R, were set using a relationship where Tc and R were equal to one another. Both Tc and R were adjusted during model calibration to improve model results. The time of concentration and storage coefficient for each subbasin are shown in Table 8.

3.3.5 Routing Reach Parameterization

The Muskingum-Cunge routing method was selected because it is based on physical parameters such as channel shape, routing reach length, and surface roughness (Manning's n value), and some of the physical parameters could be estimated using HEC-GeoHMS and the terrain data. Muskingum-Cunge routing lends itself to circumstances where limited observed data is available. Routing reach geometry was represented using eight-point cross-sections describing the geometry of the river channel and floodplain for each reach. Representative HMS Muskingum Cunge routing cross sections were derived from reach cross-section data in the Buffalo District HEC-RAS model. An example HMS cross section is shown in Figure 6.

Table 3. Curve Number (CN) Lookup Table

Land Use	Soil Type A	Soil Type B	Soil Type B	Soil Type D
Developed Open Space	54	70	80	85
Developed Low Intensity	61	75	83	87
Developed Medium Intensity	77	85	90	92
Developed High Intensity	89	92	94	95
Barren Land	54	70	80	85
Deciduous Forest	30	55	70	77
Evergreen Forest	30	55	70	77
Mixed Forest	30	55	70	77
Shrub	30	48	65	73
Grassland	30	58	71	78
Pasture	39	61	74	80
Cultivated Crops	62	71	78	81

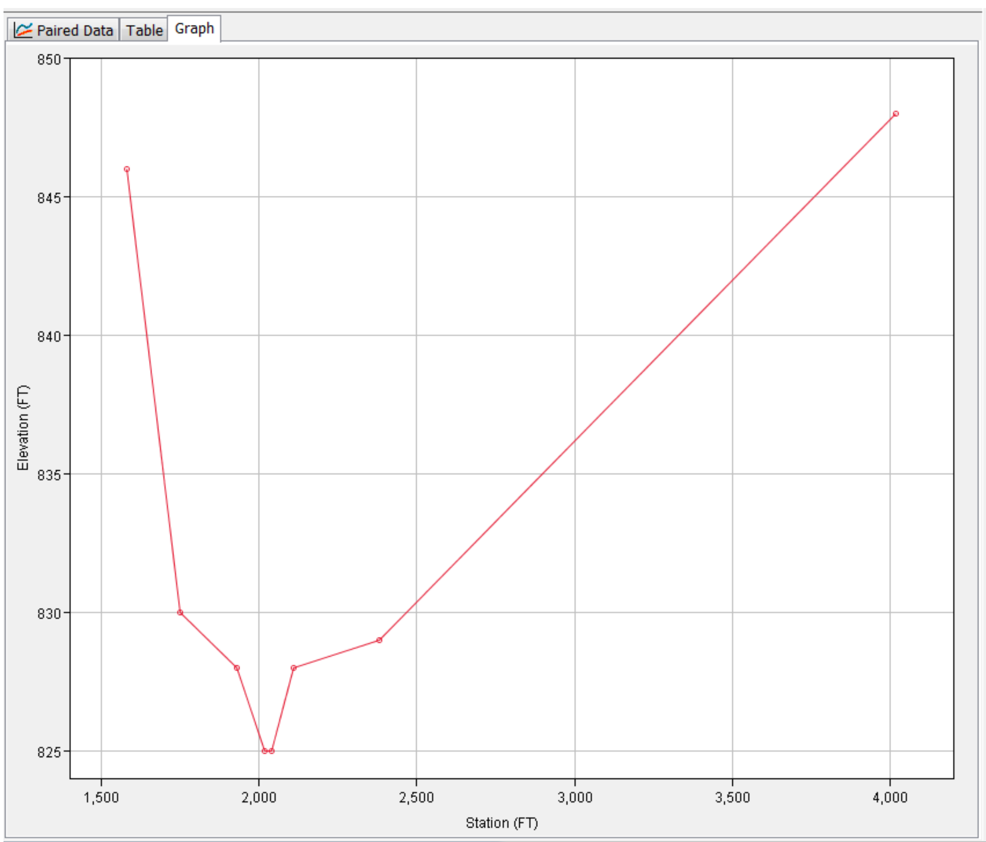

Figure 6. Example Eight-Point Cross Section used in HEC-HMS

Table 4. Area, Average Curve Number (CN), Time of Concentration (Tc) and Storage Coefficient (R) Estimates from GIS Data, by Subbasin

HMS Subbasin Name	Area (Square Miles)	Curve Number	Time of Concentration (hrs)	Storage Coefficient
W1090	65.104	80.34	15.02	24.507
W1100	77.451	79.09	17.25	28.143
W1150	13.938	79.96	13.86	22.616
W1140	3.3769	77.29	8.56	13.959
W550	27.982	79.23	19.8	32.299
W480	4.1821	74.03	10.89	17.767
W470	38.544	75.52	18.49	30.175
W890	5.6411	73.65	8.8	14.355
W730	9.7527	76.56	15.07	24.59
W880	9.8341	82.58	7.37	12.031
W740	19.502	81.37	13.68	22.316
W780	9.9525	76.22	13.69	22.33
W790	43.168	80.37	18.18	29.656
W940	11.653	82.58	7.37	12.03
W400	17.718	80.41	15.4	25.124
W930	9.6968	77.97	9.17	14.954
W580	63.512	80.53	23.33	38.064
W350	15.804	76.58	10.43	17.017
W410	48.706	77.37	14.81	24.162
W530	23.425	77.67	19	31
W520	9.9495	76.13	11.17	18.224
W990	15.593	75.65	20.67	33.725
W640	69.766	79.5	21.11	34.437
W1050	4.2263	78.41	7.15	11.66
W430	45.38	78.57	28.24	46.083
W1040	26.436	79.73	14.45	23.574
W370	83.725	80.56	30.58	49.896

3.3.6 Model Calibration to Historic Events

Model calibration is the process of adjusting model parameters to reflect watershed conditions in order to best reproduce historic flow events. Model parameters were adjusted to minimize the difference between computed and measured flows at several USGS gage locations: Blanchard River at Findlay, Blanchard River above Findlay, Blanchard River near Mt. Blanchard, Eagle Creek above Findlay, Lye Creek above Findlay, Riley Creek, and Blanchard River at Ottawa.

Multiple storm events were used to calibrate and validate the model. The storm events selected for calibration and verification were mostly from recent events since: 1) Data is more readily available for recent events; and 2) Recent events reflect present day land use in the watershed. The historic events chosen for model calibration included the October 2011, September 2011, February 2008, and August 2007 flood events. Model calibrations were performed using observed data from the October 2011 storm event. Model verification was performed for the September 2011, February 2008, and August 2007 flood events using model parameter values established under calibration to the October 2011 event.

The calibration process started with a focus on adjustments to the SCS CN values for headwater subbasins. Subbasins with gauged stream flow data are Eagle Creek, Lye Creek, Riley Creek, and Blanchard River at Mt. Blanchard. Headwater subbasins have little influences from routing; therefore they can be used for adjusting basin parameter like SCS CN parameters and Clark transformation parameters. After a good fit between simulated and observed hydrographs was achieved, these calibrated subbasins were used as a basis for adjusting other subbasins with similar basin characteristics. Plots comparing simulated and observed hydrographs for the October 2011 event for subbasins of Eagle Creek, Lye Creek, Blanchard River at Mt. Blanchard, and Riley Creek are shown in Figures 7-10, respectively.

The next calibration step involved adjusting routing parameters. Reach flow routing was modeled using the Muskingum-Cunge method. Representative eight-point cross sections for each routing reach were derived from the RAS model cross sections. Representative Manning's roughness coefficients were estimated from aerial photography. Manning's roughness coefficients were then adjusted to achieve a good fit to observed data at the following gages: Blanchard River above Findlay, Blanchard River at Findlay, and Blanchard River at Ottawa. Plots comparing simulated and observed hydrographs for the October 2011 event along Blanchard River above Findlay, at Findlay, and Ottawa are shown in Figures 11 through 13, respectively. Calibration results for the October 2011 flood event are summarized in Table 9.

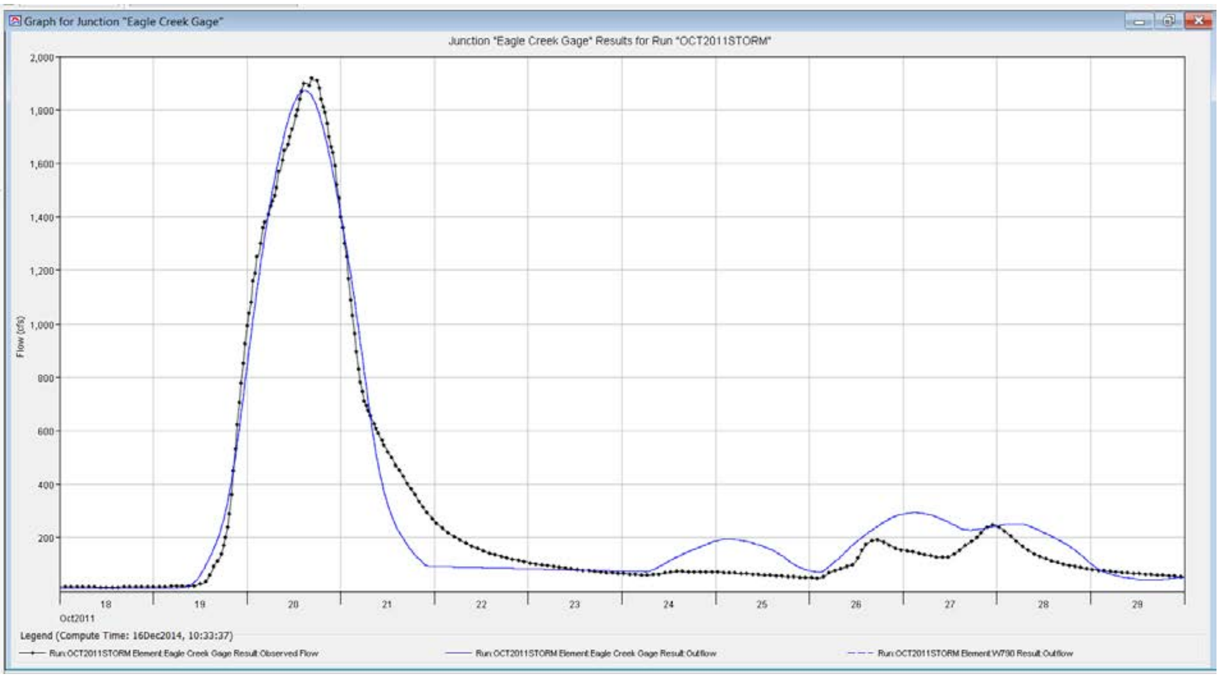

Figure 7. Eagle Creek Gage: Simulated vs. Observed Hydrographs for October 2011 Flow Event

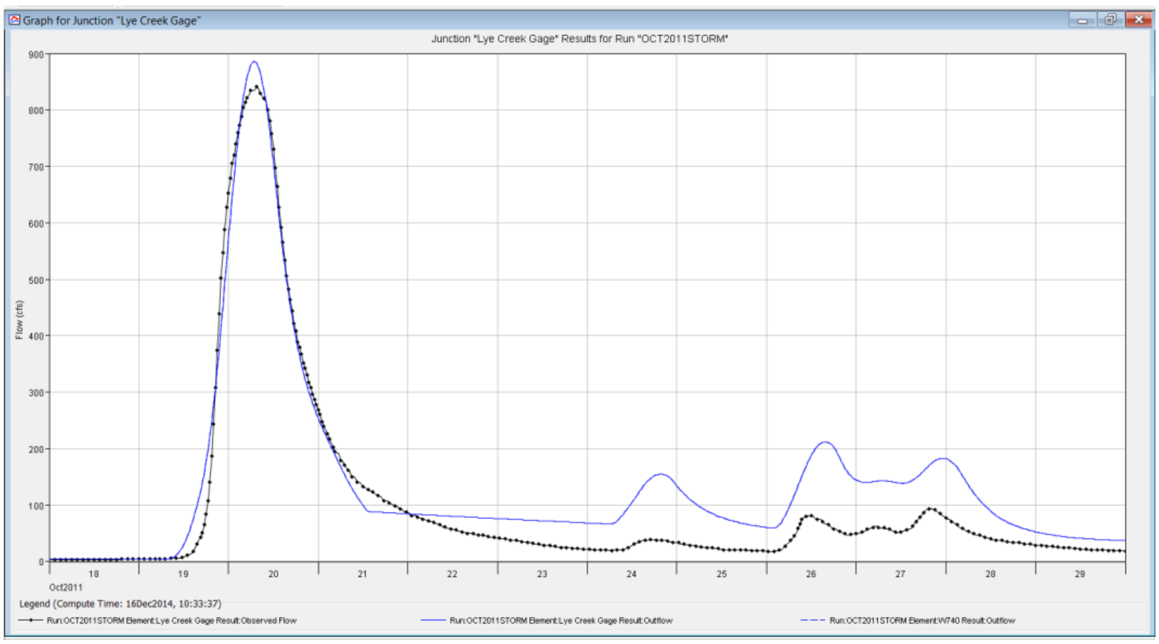

Figure 4. Lye Creek Gage: Simulated vs. Observed Hydrographs for October 2011 Flow Event

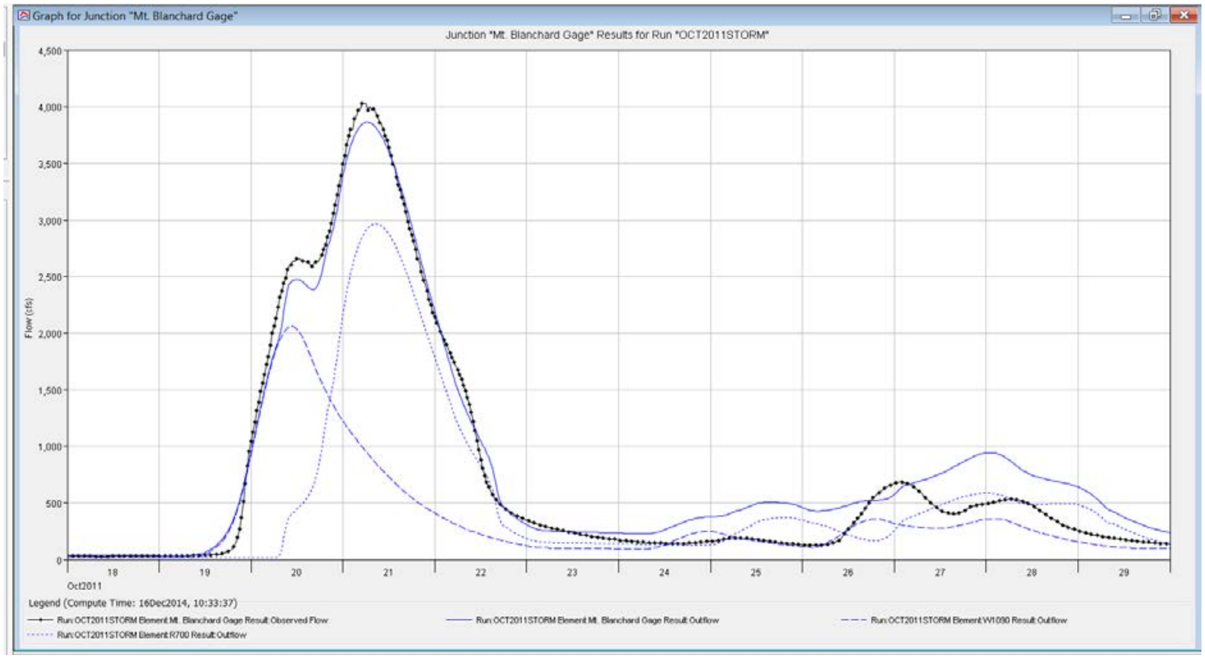

Figure 9. Blanchard River at Mt. Blanchard Gage: Simulated vs. Observed Hydrograph for October 2011 Flow Event

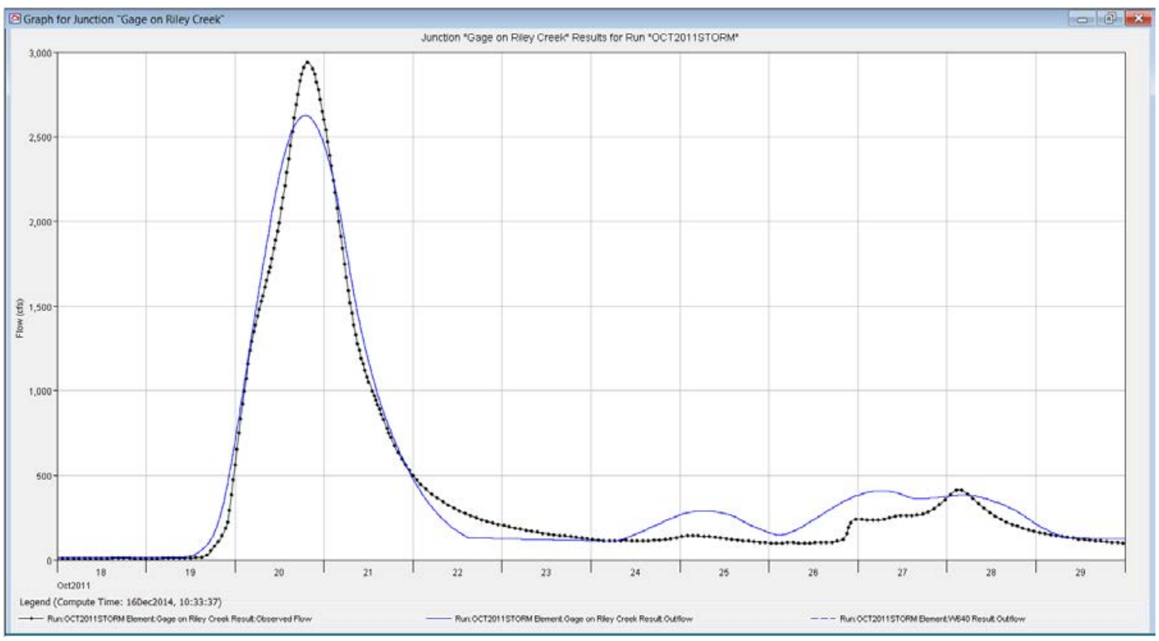

Figure 10. Riley Creek Gage: Simulated vs. Observed Hydrographs for October 2011 Flow Event

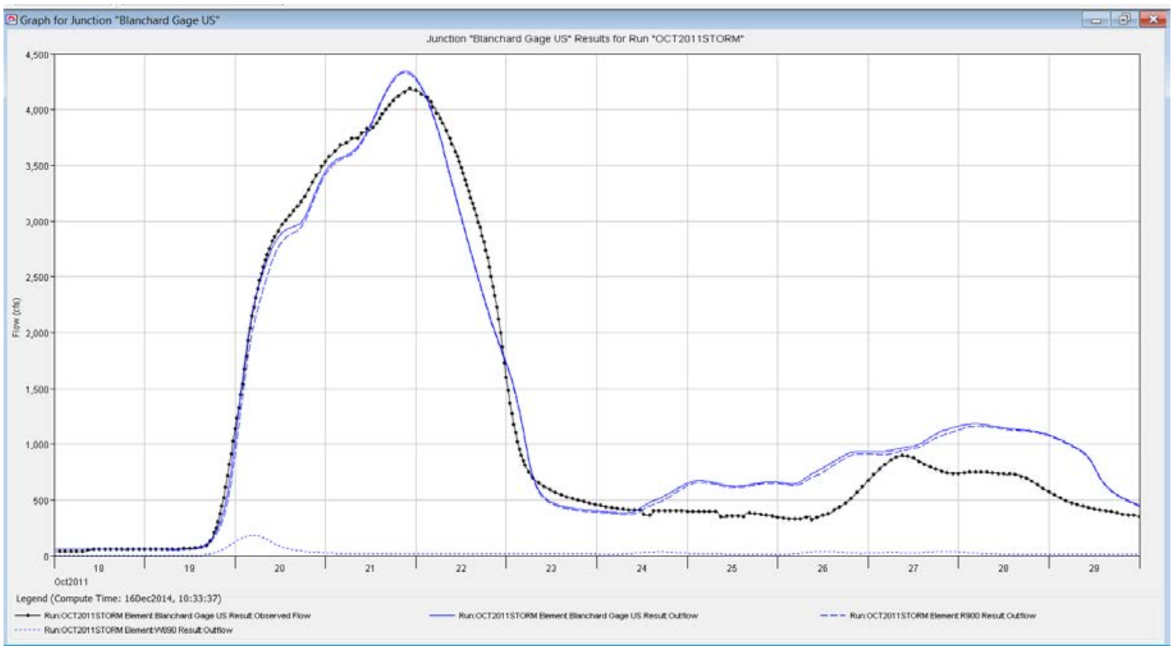

Figure 5. Blanchard River above Findlay Gage: Observed vs. Simulated Hydrograph for October 2011 Flow Event

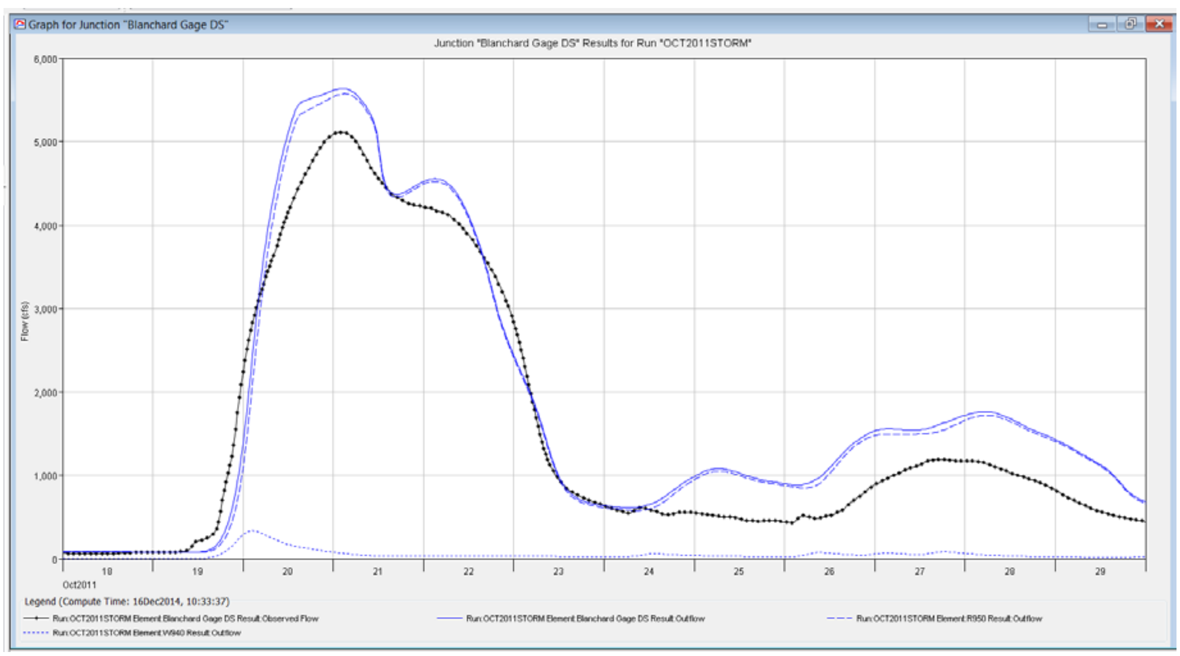

Figure 6. Blanchard River at Findlay Gage: Simulated vs. Observed Hydrographs for October 2011 Flow Event

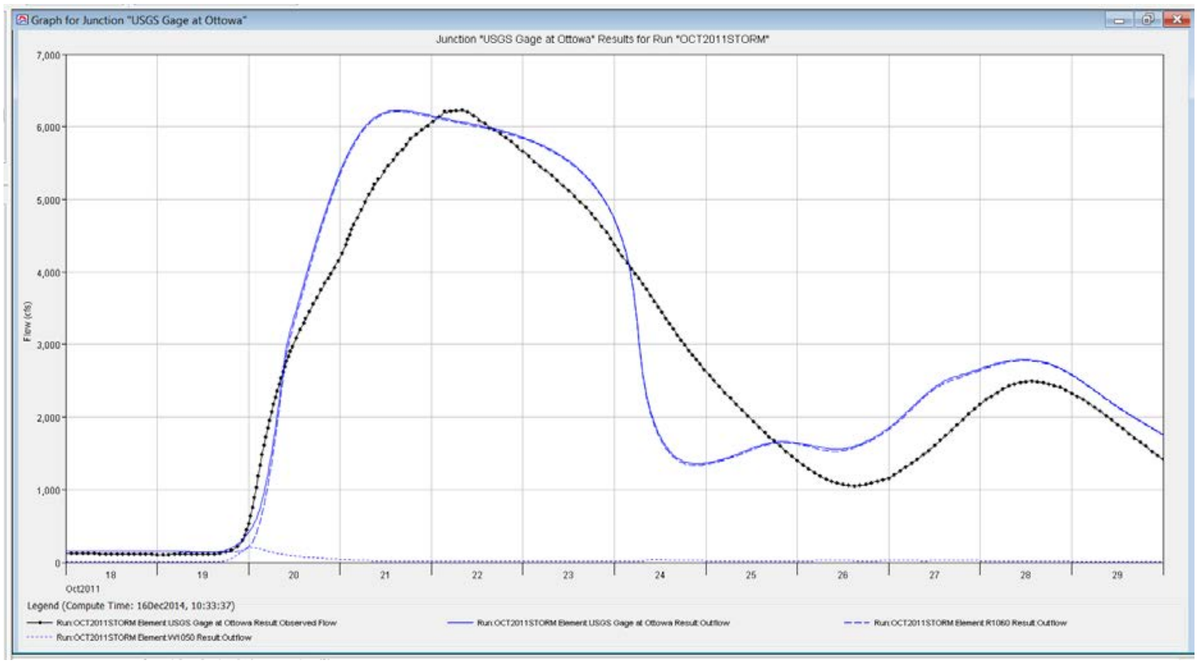

Figure 7. Blanchard River at Ottawa Gage: Simulated vs. Observed Hydrographs for October 2011 Flow Event

Table 5. Comparison of Computed and Measured Peak Flows for the October 2011 Flow Event

Location	Simulated Peak Flow (cfs)	Observed Peak Flow (cfs)	Percent Difference (%)
Blanchard River at Findlay, OH	5638	5110	10.3
Blanchard River above Findlay, OH	4344	4190	3.7
Blanchard River at Mt. Blanchard, OH	3864	4030	- 4.1
Blanchard River at Ottawa, OH	6229	6230	0.0
Eagle Creek above Findlay, OH	1873	1920	-2.4
Lye Creek above Findlay, OH	887	841	5.5
Riley Creek at Pandora, OH	2627	2940	-10.6

3.3.7 Model Validation

Model validation was performed using the August 2007 record flood, and the September 2011 and February 2008 events. Only the Blanchard River at Findlay gage was available during the August 2007 flood. The August 2007 flood observed hydrograph compares very favorably with the simulated hydrograph, as shown in Figure 14. The HMS model simulated a peak discharge of 15,324 cfs compared to a gage recording of 14,500 cfs. The calibration effort was focused on matching peak flows for larger storm events, for the purpose of evaluating flood risk management alternatives, than for simulating base flow or smaller flow event.

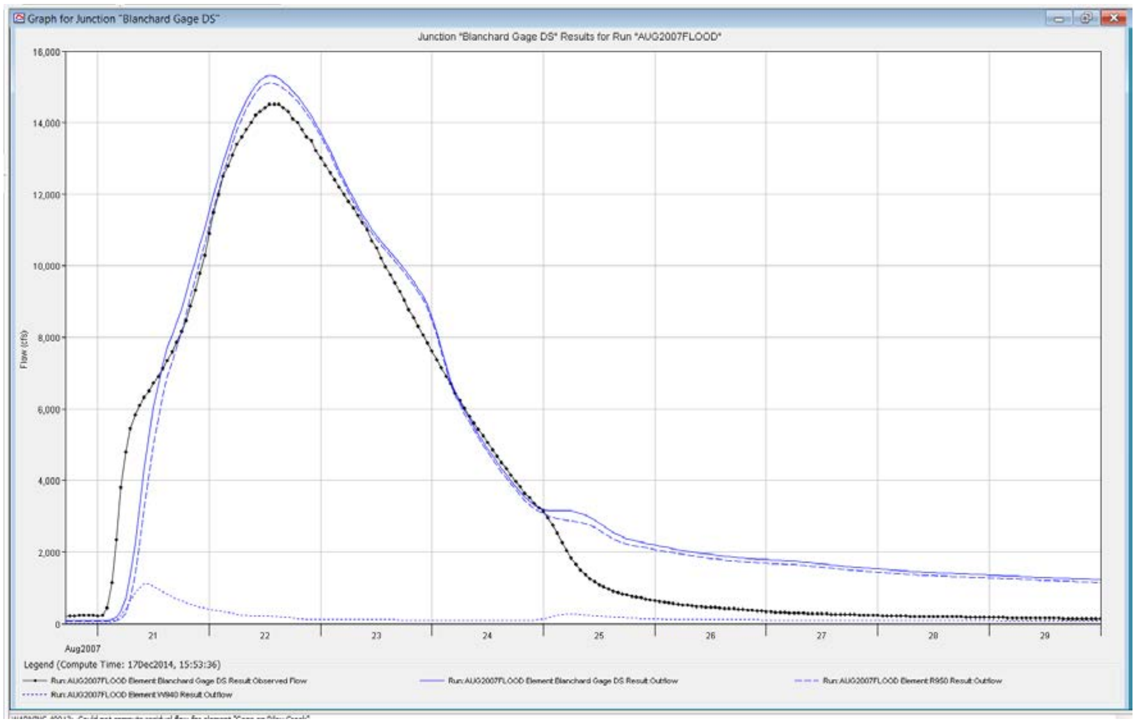

Figure 14. Blanchard River Gage: Simulated vs. Observed Hydrographs for August 2007 Flood Event

The September 2011 flow event was used for model verification. Plots comparing simulated and observed hydrographs for the September 2011 event are shown in Figures 15 through 21 for Eagle Creek, Lye Creek, Blanchard River at Mt. Blanchard, Blanchard River above Findlay, Blanchard River at Findlay, Riley Creek, and Blanchard River at Ottawa. Most of the subbasins provide favorable comparison of observed and simulated hydrograph. A combination of problems with the radar rainfall data, soil moisture condition and observed gage data in some of the subbasins makes verification difficult for the September 2011 as shown in Figure 21. Verification result for the September 2011 flood event is summarized in Table 10.

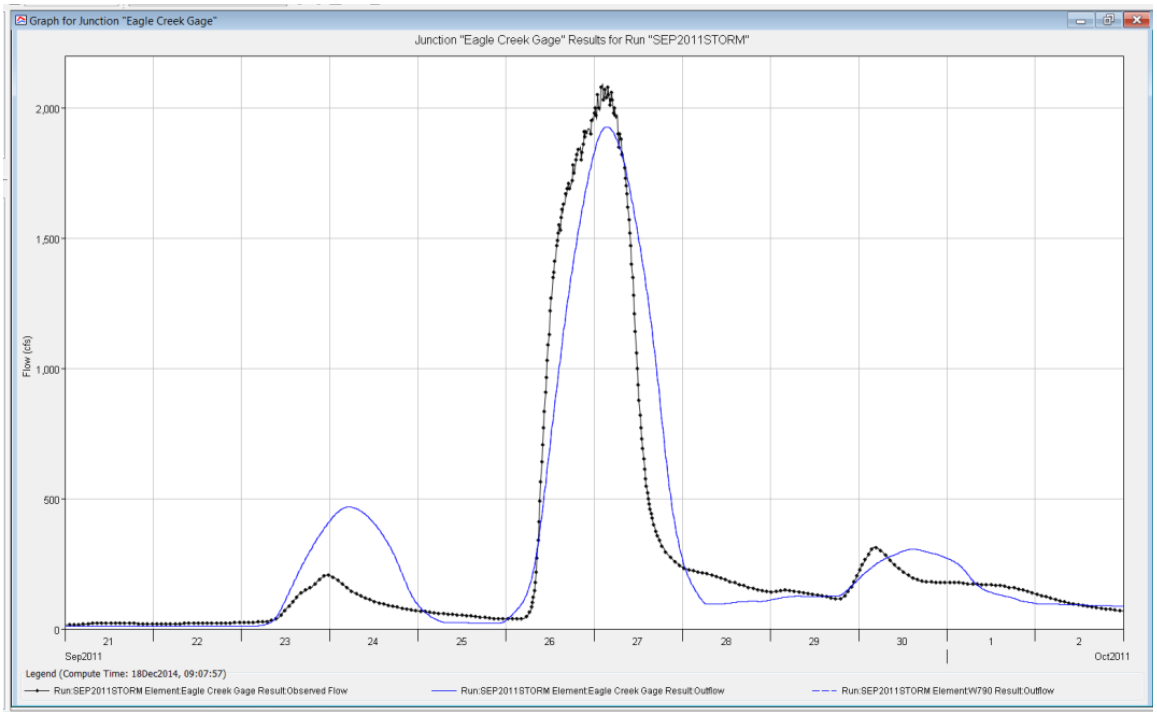

Figure 15. Eagle Creek Gage: Simulated vs. Observed Hydrograph for September 2011 Storm Event

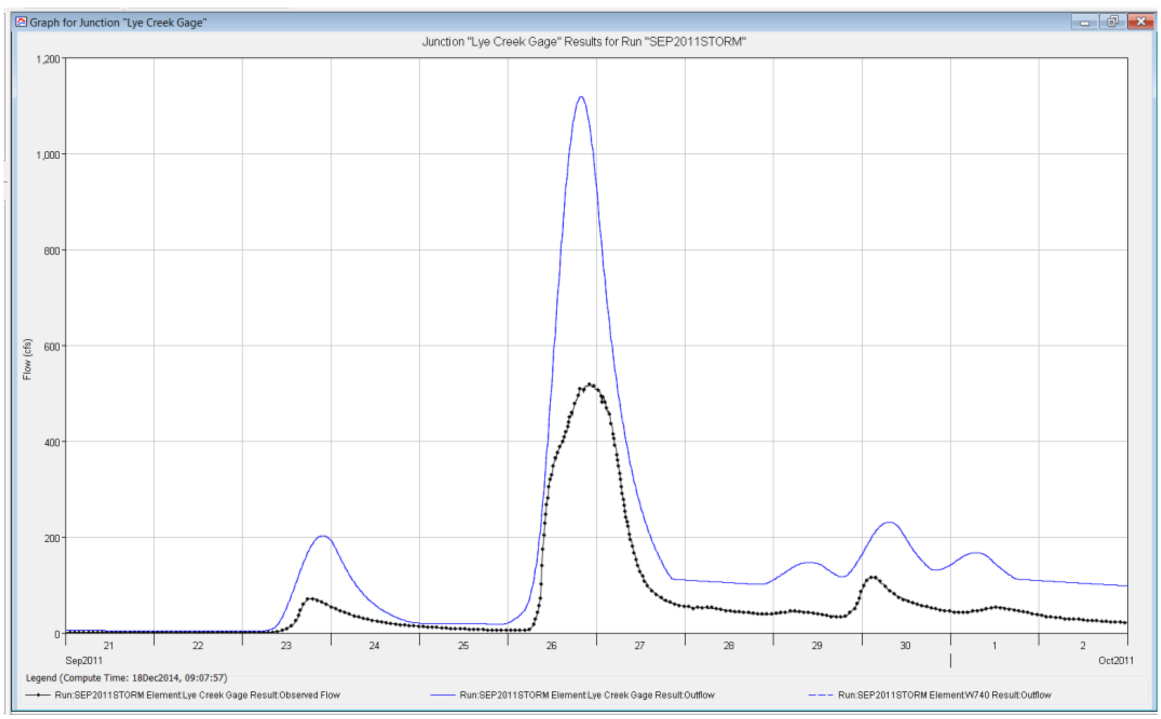

Figure 168. Lye Creek Gage: Simulated vs. Observed Hydrograph for September 2011 Storm Event

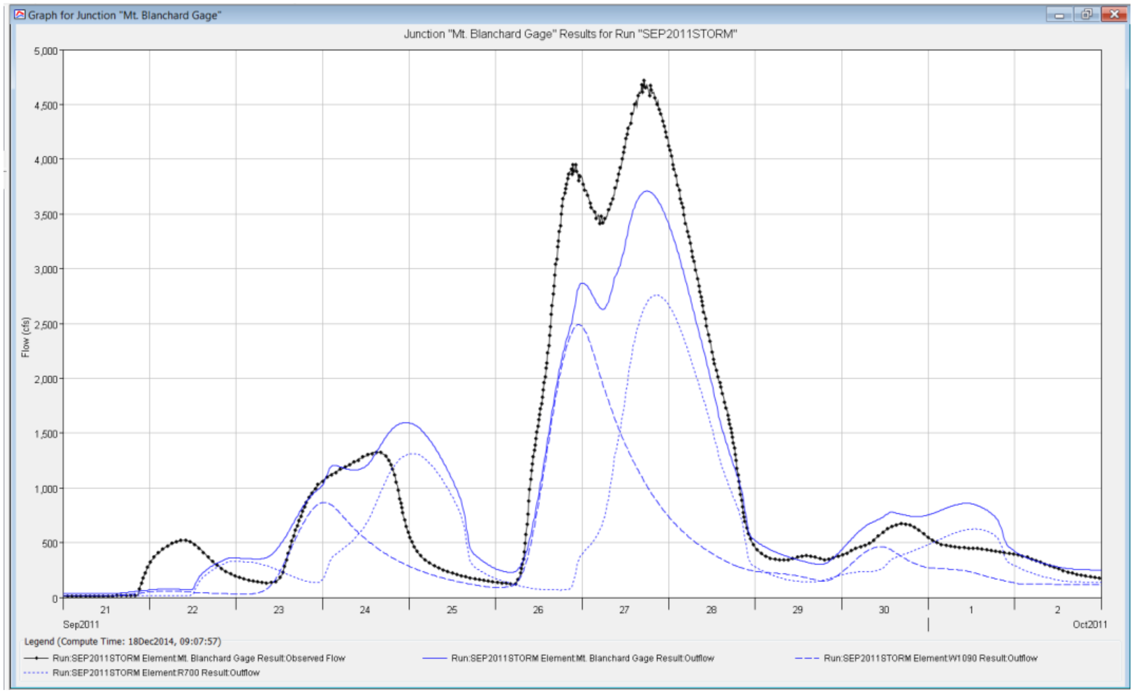

Figure 17. Blanchard River at Mt. Blanchard Gage: Simulated vs. Observed Hydrographs for September 2011 Storm Event

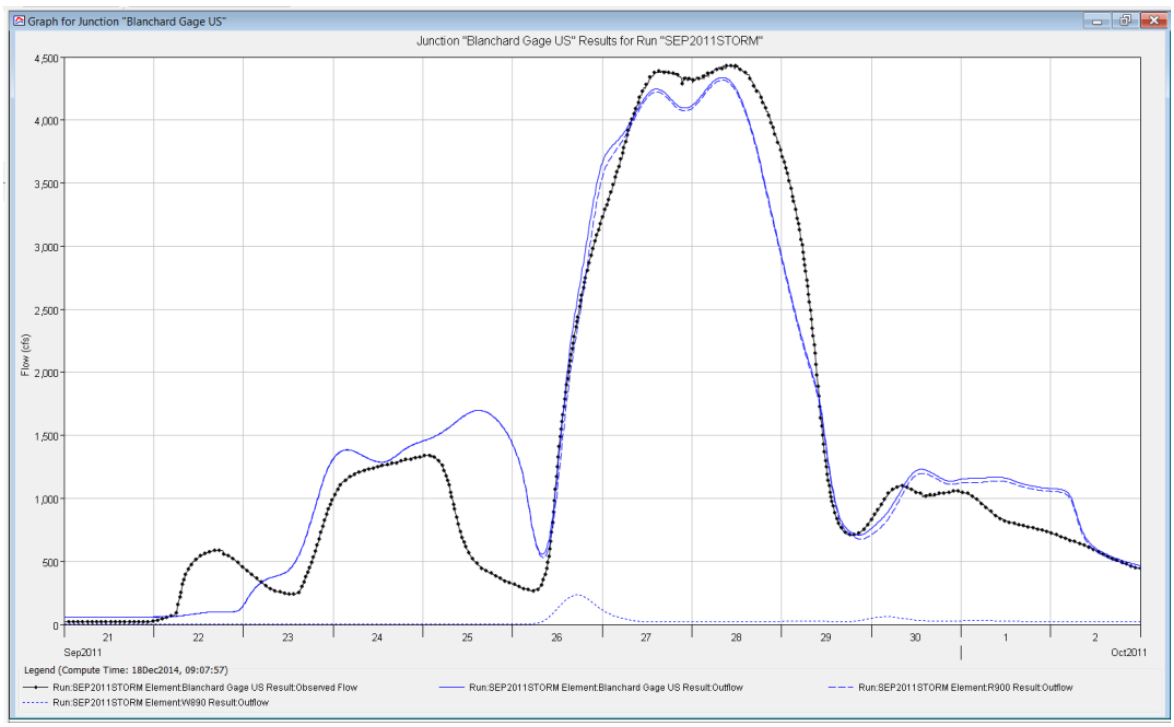

Figure 18. Blanchard River above Findlay Gage vs. Observed Hydrograph for September 2011 Storm Event

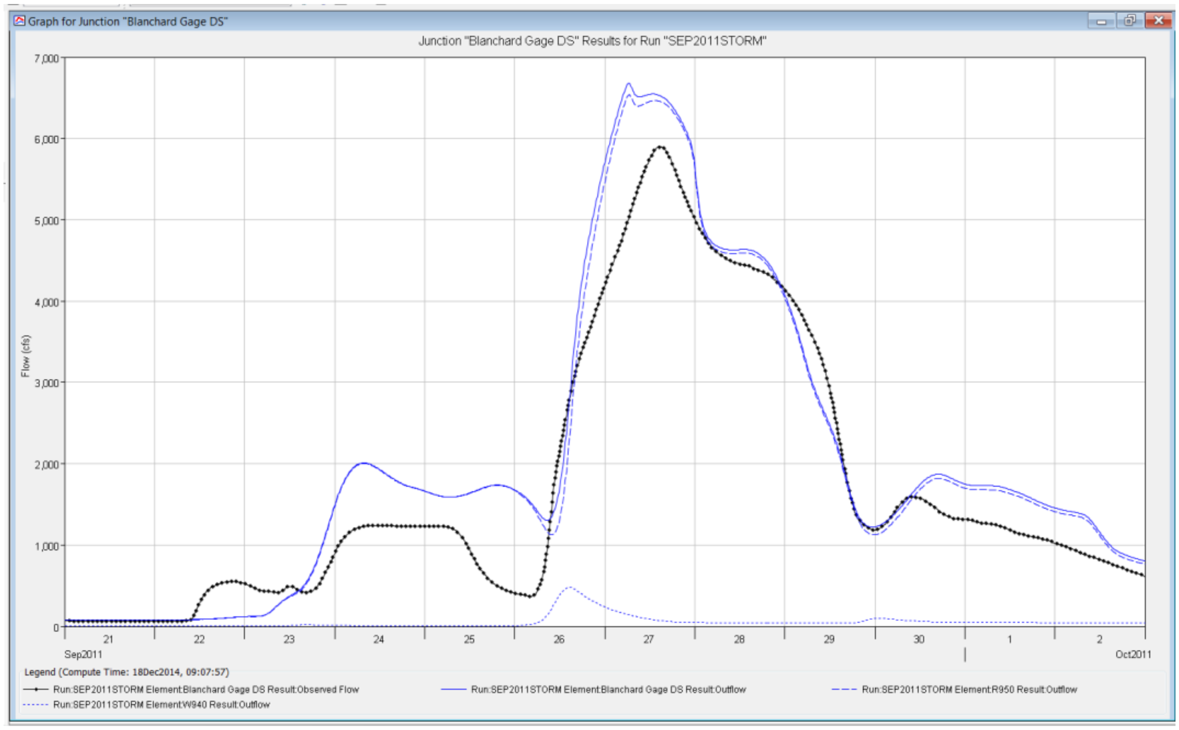

Figure 19. Blanchard River at Findlay Gage: Simulated vs. Observed Hydrographs for September 2011 Storm Event

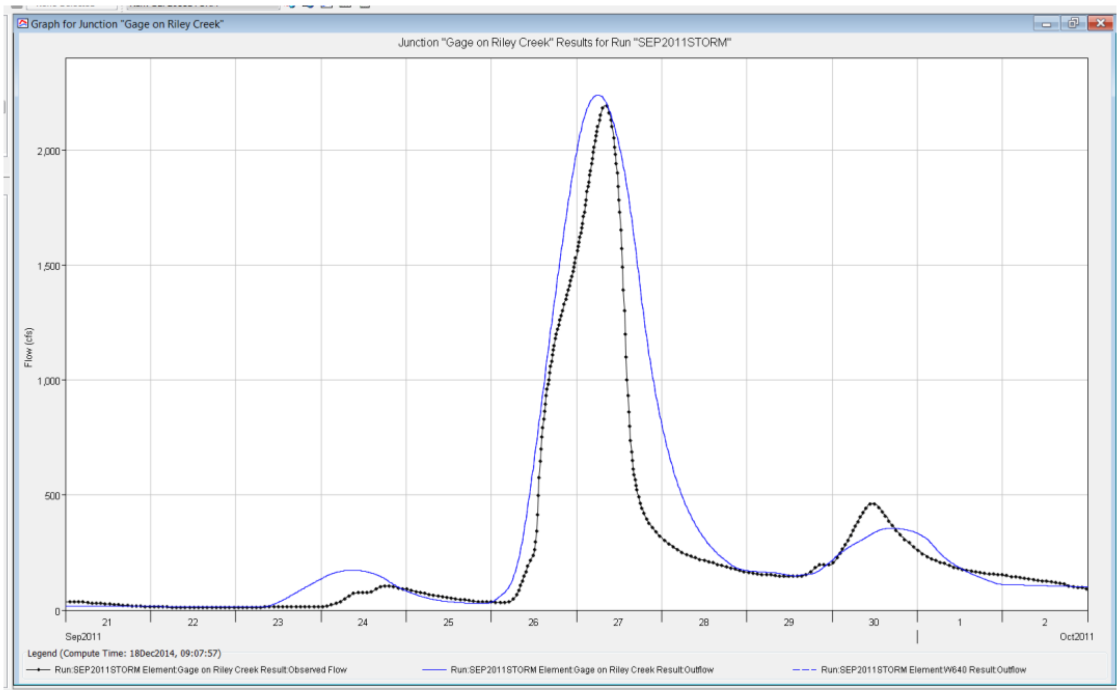

Figure 20. Riley Creek Gage: Simulated vs. Observed Hydrograph for September 2011 Storm Event

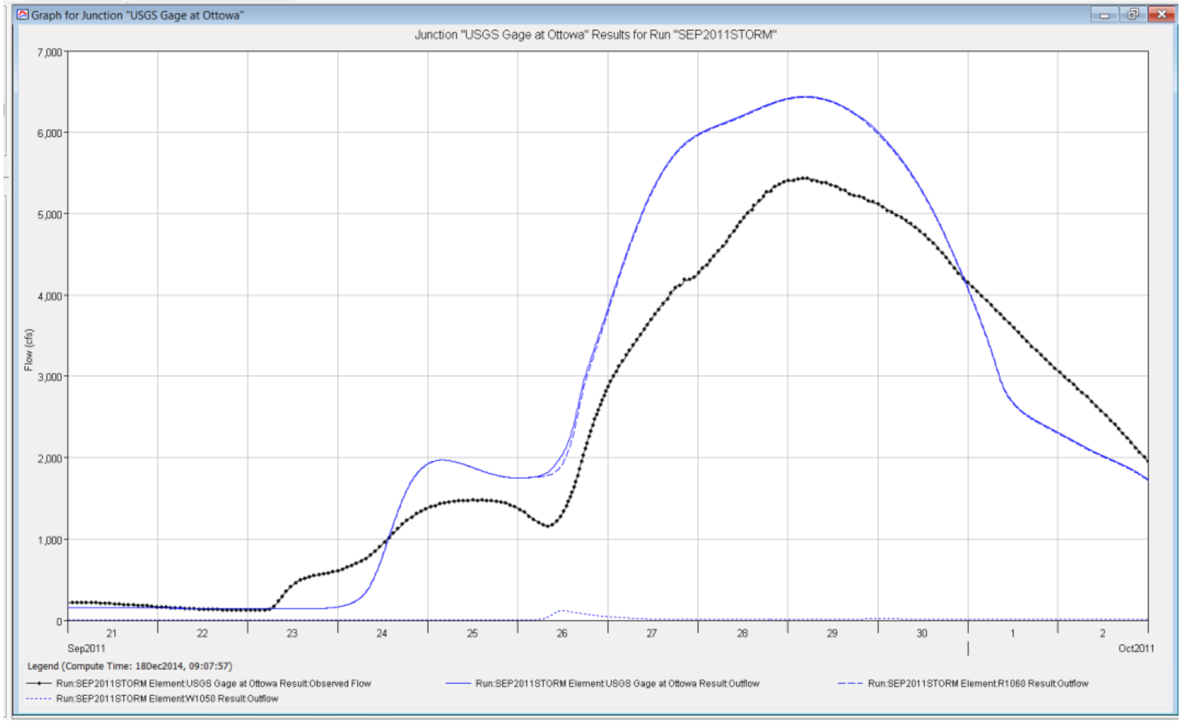

Figure 21. Blanchard River at Ottawa Gage: Simulated vs. Observed Hydrograph for September 2011 Storm Event

Plots comparing simulated and observed hydrographs for the February 2008 event are shown in Figures 22 through 25 for Eagle Creek, Blanchard River at Mt. Blanchard, Blanchard River above Findlay, and Blanchard River at Findlay, respectively. Validation results for the February 2008 flood event are summarized in Table 11. The final calibrated parameter set is shown in Table 12.

Table 6. Comparison of Simulated and Observed Peak Flows for the September 2011 Storm Event

Location	Simulated Peak Flow (cfs)	Observed Peak Flow (cfs)	Percent Difference (%)
Blanchard River at Findlay, OH	6683	5900	13.3
Blanchard River above Findlay, OH	4339	4440	-2.3
Blanchard River at Mt. Blanchard, OH	3709	4720	-21.4
Blanchard River at Ottawa, OH	6439	5440	18.4
Eagle Creek above Findlay, OH	1927	2090	-7.8
Lye Creek above Findlay, OH	1119	520	115.2
Riley Creek at Pandora, OH	2239	2190	2.2

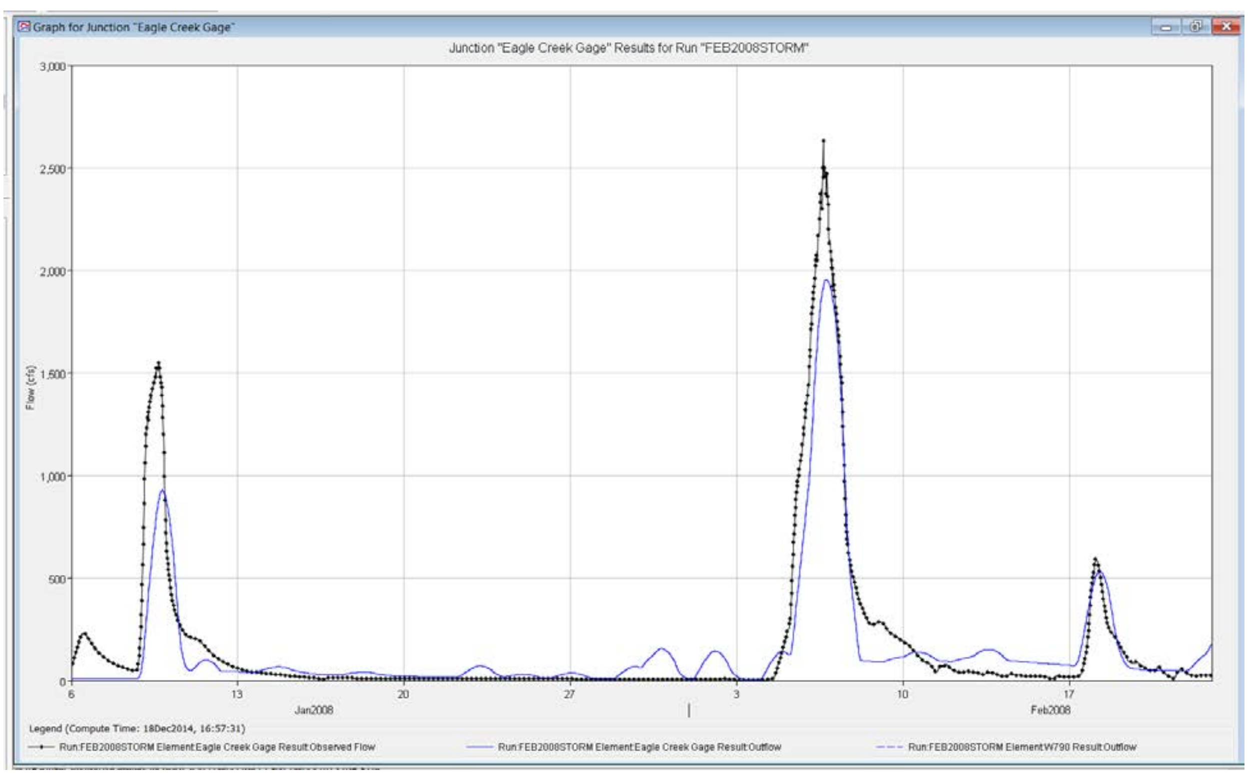

Figure 22. Eagle Creek Gage: Simulated vs. Observed Hydrograph for February 2008 Storm Event

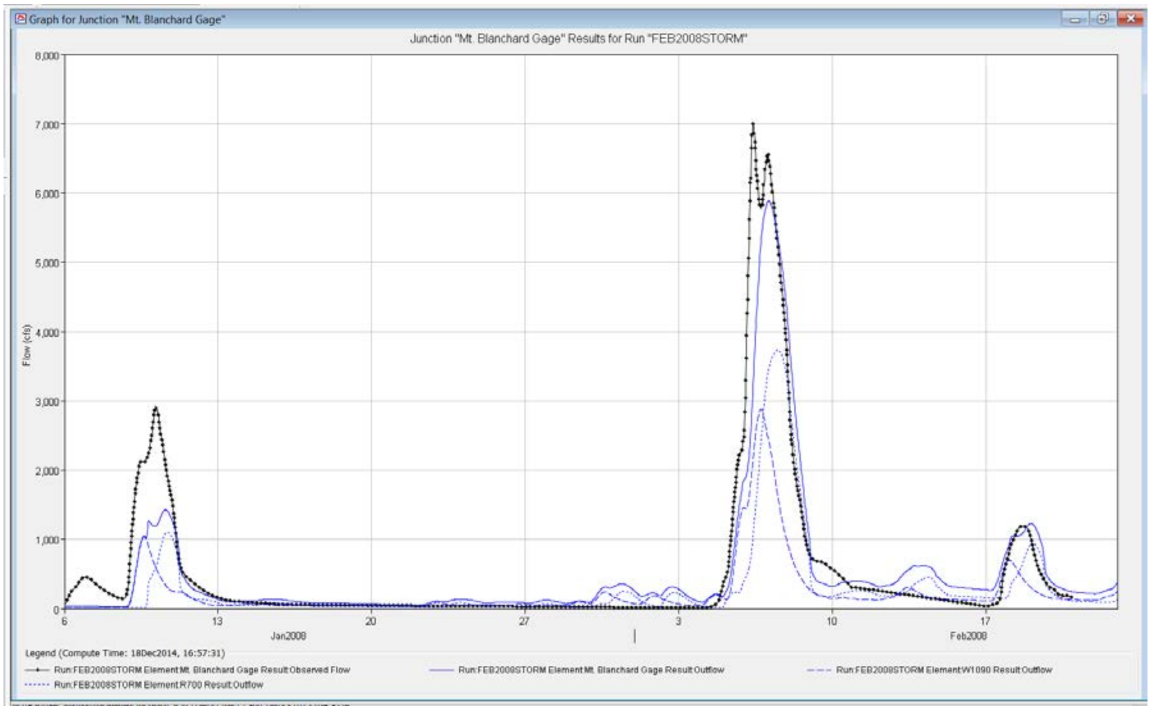

Figure 23. Blanchard River at Mt. Blanchard Gage: Simulated vs. Observed Hydrograph for February 2008 Storm Event

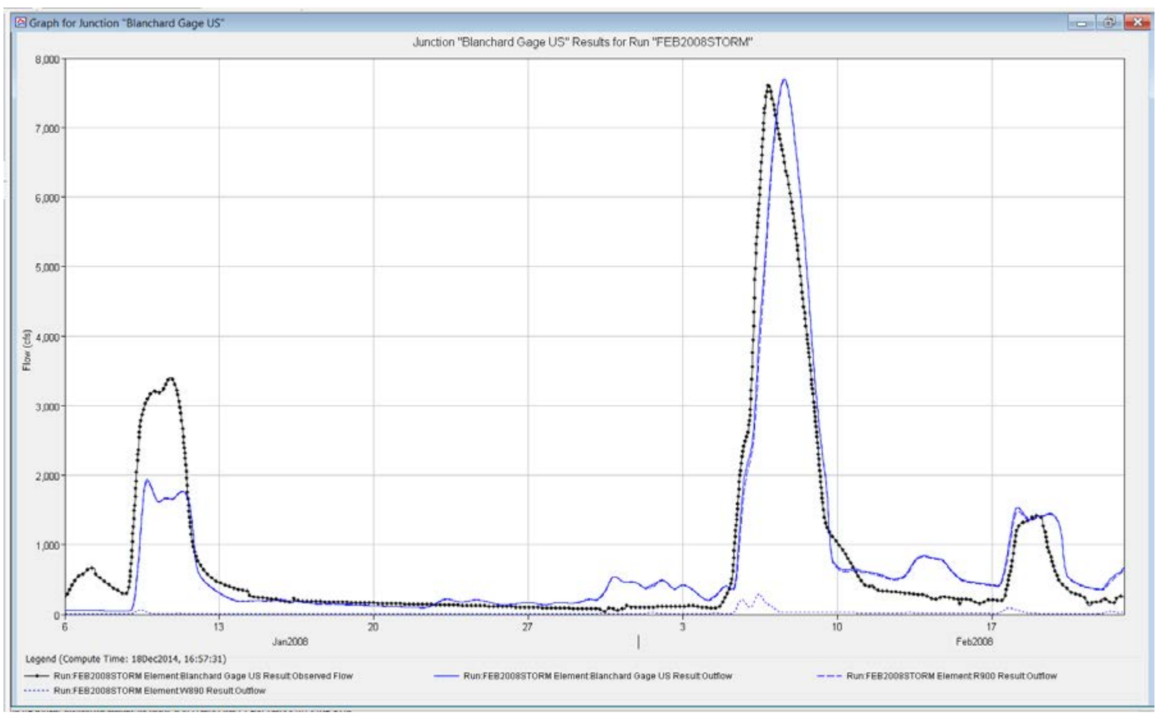

Figure 24. Blanchard River above Findlay Gage: Simulated vs. Observed Hydrograph for February 2008 Storm Event

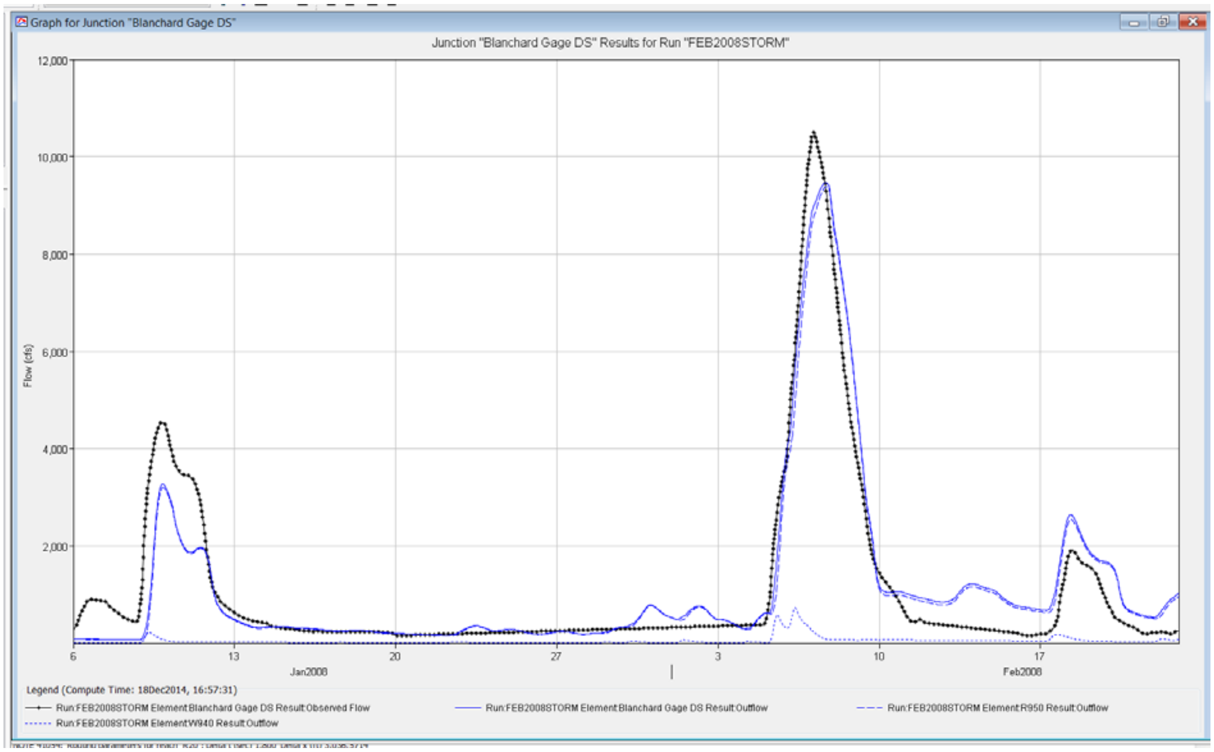

Figure 25. Blanchard River at Findlay Gage: Simulated vs. Observed Hydrograph for February 2008 Storm Event

Table 7. Comparison of Simulated and Observed Peak Flows for the February 2008 Flow Event

Location	Simulated Peak Flow (cfs)	Observed Peak Flow (cfs)	Percent Difference (%)
Blanchard River at Findlay, OH	9466	10500	-9.8
Blanchard River above Findlay, OH	7702	7600	1.3
Blanchard River at Mt. Blanchard, OH	5880	7000	-16.0
Blanchard River at Ottawa, OH	11341	No Data	-
Eagle Creek above Findlay, OH	1954	2630	-25.7
Lye Creek above Findlay, OH	1056	1410	-25.1
Riley Creek at Pandora, OH	2768	No Data	-

Table 8. Calibrated HEC-HMS Model Parameters

HMS Subbasin Name	Area (Square Miles)	Curve Number	Time of Concentration (hrs)	Storage Coefficient
W1090	65.104	87.7	18.35	18.793
W1100	77.451	86.7	33.078	8.21
W1150	13.938	84.8	16.4	5.6
W1140	3.3769	77.9	3.8	5.8
W550	27.982	84.8	17.3	30.4
W480	4.1821	73.8	7.7	8.1
W470	38.544	88.7	24.3	21.4
W890	5.6411	73.8	12.2	6.3
W730	9.7527	76.56	15.07	24.59
W880	9.8341	82.58	7.37	12.031
W740	19.502	87.1	16	9.1
W780	9.9525	76.22	13.69	22.33
W790	43.168	90.9	34.8	4.7
W940	11.653	82.58	7.37	12.03
W400	17.718	80.41	15.4	25.124
W930	9.6968	78.05	9.2	14.996
W580	63.512	81.55	23.43	38.195
W350	15.804	76.557	10.448	17.031
W410	48.706	78.2	14.86	24.3
W530	23.425	77.64	19	31
W520	9.9495	76.148	11.131	18.28
W990	15.593	75.714	20.719	33.808
W640	69.766	88.6	33.5	10.7
W1050	4.2263	78.4	4.2	11.6
W430	45.38	78.57	28.24	46.083
W1040	26.436	79.73	14.45	23.574
W370	83.725	80.56	30.58	49.896

3.3.8 Summary of Results

A hydrologic model was developed for the Blanchard River watershed in northwest Ohio. The model was developed using the USACE HEC-HMS model and was calibrated to recent high flow events.

The calibration results for the October 2011 events summarized above appear reasonable. Values for subbasin parameters such as the SCS curve number are within reasonable ranges and reflect the land use and hydrologic soil type in each subbasin. The time of concentration and storage coefficient values are reasonable as demonstrated by simulated and observed hydrograph comparisons for both calibration and verification events. The routing parameters reflect the channel geometry and overbank areas of the HEC-RAS cross sections and the Manning’s roughness coefficients reflect observations from aerial photography. The simulated and observed hydrographs for all gages in the Blanchard River watershed are in close agreement which demonstrates selection of reasonable routing parameter values.

The calibrated model was used to develop frequency flows for use in hydraulic modeling. HMS model simulated frequency flows at the Findlay gage location are shown in Table 13.

Table 13. Model Simulated Frequency Flows for Blanchard River at Findlay Gage

Frequency	Peak Flow (cfs)
50% Annual Chance (2-year)	3,832
20% Annual Chance (5-year)	5,770
10% Annual Chance (10-year)	7,555
4% Annual Chance (25-year)	9,735
2% Annual Chance (50-year)	11,301
1% Annual Chance (100-year)	13,033
0.4% Annual Chance (250-year)	15,429
0.2% Annual Chance (500-year)	17,867

4. HYDRAULIC MODELING OF BLANCHARD RIVER

4.1 Introduction

A hydraulic model was developed for the Blanchard River and its major tributaries in the vicinity of the project site in Findlay, OH. This effort included a review of the Buffalo District's previous HEC-RAS model, necessary updates to the model, and further enhancements made through calibrating the model to match the 2007 flood. The hydraulic model was used to evaluate a set of flood risk management alternatives to inform selection of the TSP.

4.2 Hydraulic Model Update

4.2.1 Revised HEC-RAS Model

The previous Buffalo District HEC-RAS model of the Blanchard River was revised to closely match the baseline (existing) condition. The existing HEC-RAS model geometry was updated to reflect the available lidar data and latest aerial photography. The HEC-GeoRAS software was used to update the geometry using the latest lidar data. All structure geometry was kept unchanged except for roughness coefficients during the calibration process.

Ineffective flow areas were assigned to cross sections as needed. Ineffective flow areas are areas within a cross section where flow storage may occur but flow rate is negligible due to topography, structural obstructions, and/or divided flows. These areas were determined based on engineering judgment upon review of conditions in the field. A typical Blanchard River HEC-RAS model cross section with ineffective flow areas is shown in Figure 26.

Contraction and expansion coefficients are used in HEC-RAS in computing the head losses that occur between cross sections due to flow contraction or expansion, respectively. As recommended by the HEC-RAS User Manual, coefficients of 0.1 and 0.3 were used for contraction and expansion, respectively for typical variations between cross sections, while coefficients of 0.3 and 0.5 were used at bridges and culverts.

Channel and floodplain roughness coefficients were developed from the latest aerial photography and available river channel photographs. Typically, roughness coefficients for the river and creek banks were higher than coefficients for the channel bottom, to reflect the presence of vegetation and debris on the banks. The Manning's n values for the project area were calibrated against 2007 flood water surface elevations. During model calibration runs, it was discovered that initial roughness coefficients were either under- or over-estimated. As the calibration was based on the record flood event of August 2007, the calibrated parameterization is expected to more closely match larger flow events than more typical flow conditions.

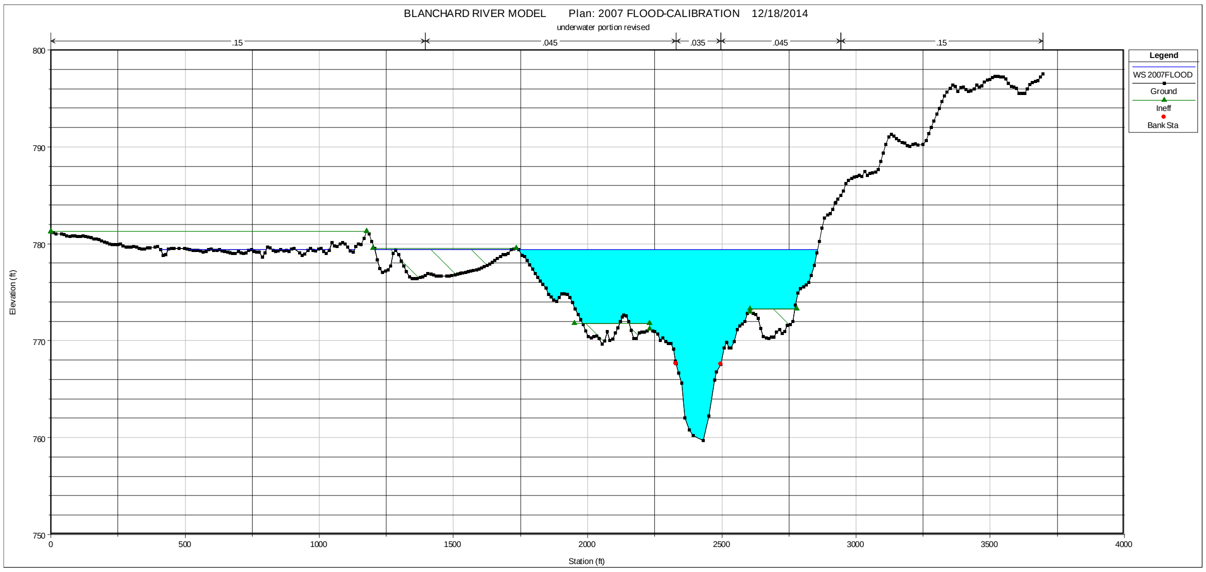

Figure 26 Typical Blanchard River HEC-RAS Model Cross Section Showing Ineffective Flow Areas (Striped)

4.2.2 Calibration of HEC-RAS Model

The Blanchard River hydraulic model was calibrated against high water marks measured during the August 2007 flood event. The procedure involved assigning peak flow data from HEC-HMS simulations of the August 2007 storm events, and then comparing the stages computed in HEC-RAS to actual measured stage data. Parameters adjusted in the hydraulic model during calibration were Manning's n, ineffective flow areas, and expansion and contraction coefficients. The few streams that were ungaged did not undergo calibration due to a lack of measured stage data. Figure 27 maps surveyed high water marks from the August 2007 flood event. Flood water surface elevations (WSELs) at each observation location were assigned approximate river stations for the purpose of comparison with simulated WSEL. The comparison of simulated WSEL and measured high water marks for the August 2007 flood is shown in Figure 28. The model calibration provided a good fit to the observed data.

4.2.3 Blanchard to Lye Overflow

The existing Blanchard River to Lye Creek overflow area was modeled as a "lateral weir structure" in HEC-RAS. Elevations for this "structure" were obtained from available lidar data. It was assumed that water flowing over Township Road 240 on the left bank of the Blanchard River just south and upstream of Findlay added to Lye Creek peak flows and contributed to flooding of the Lye Creek floodplain. Figure 29 shows the location of the Blanchard River to Lye Creek overflow area during large flood events. Figure 30 shows the profile of Township Road 240 that was used to define the "lateral weir structure" in the HEC-RAS model and thus simulate flow over the roadway during flood events.

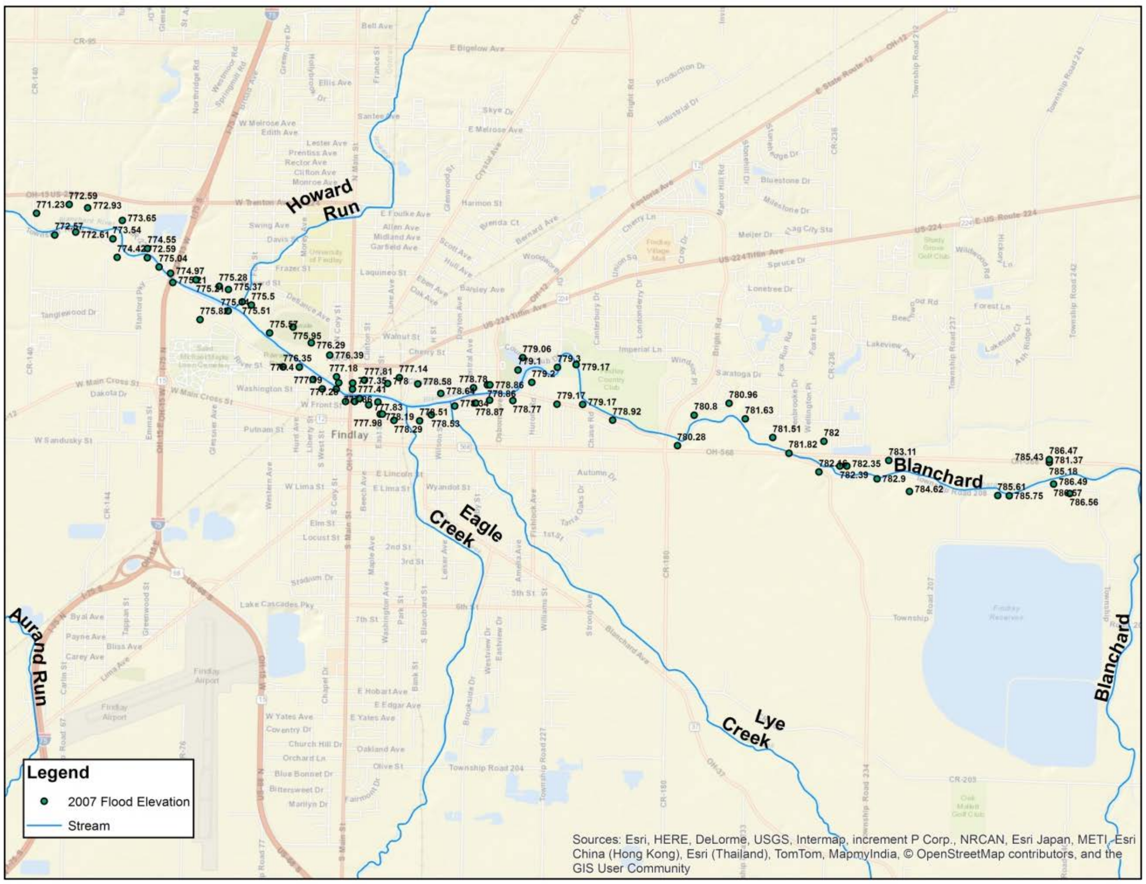

Figure 27 Surveyed 2007 Flood Elevation Observations and Locations along the Blanchard River (Source: FEMA)

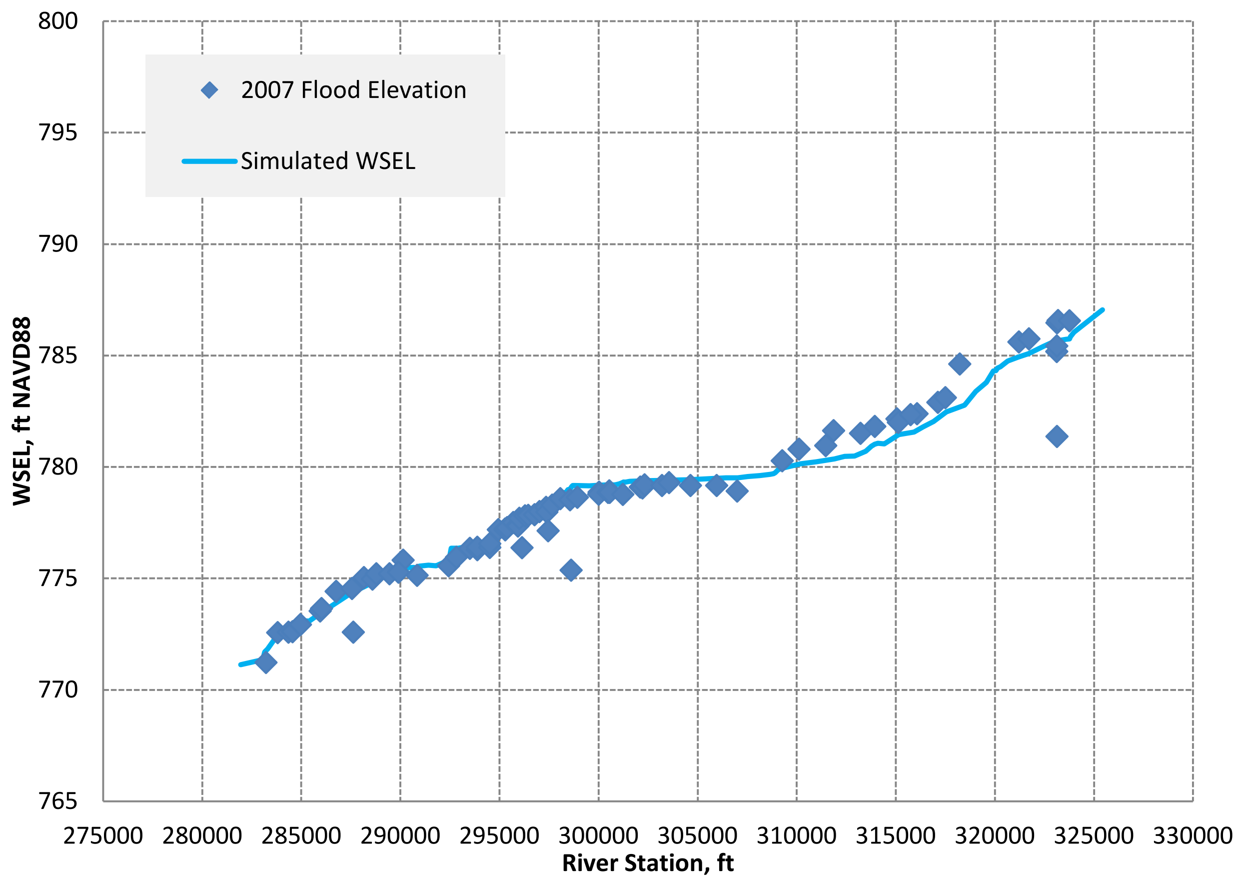

Figure 28. Comparison of HEC-RAS Simulated and Observed Water Surface Elevations for the 2007 Flood

4.2.4 Baseline (Existing Condition) Determination

The calibrated HEC-RAS model was used to simulate the existing, or baseline, condition of the Blanchard River and its tributaries in the vicinity of Findlay, OH. Frequency flows derived from the HEC-HMS simulations were used to determine baseline conditions water surface elevations for the 50%, 20%, 10%, 4%, 2%, 1%, 0.4%, and 0.2% annual chance events (i.e. the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year return periods). These frequency peak flows from HEC-HMS model simulations, were used as steady state flows in the HEC-RAS model to evaluate existing conditions. These baseline water surface elevations were then used in the HEC Flood Damage Analysis (HEC-FDA) model to assess monetary damages associated with each frequency flow event. Figure 31 shows a simulated 1% annual chance (100-year) event water surface elevation along the Blanchard River in Findlay, OH. Figure 32 shows a map of the 1% annual chance (100-year) event floodplain as simulated in the HEC-RAS model.

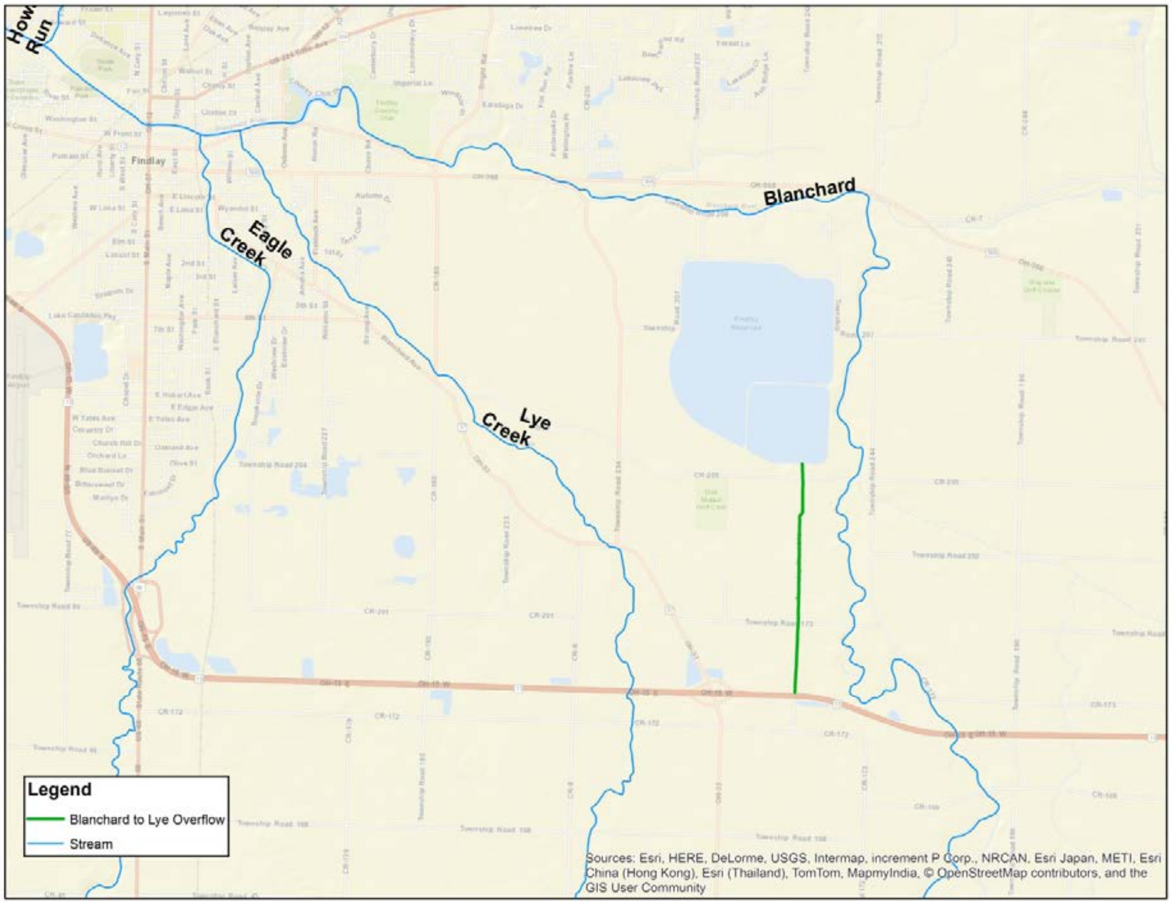

Figure 29 Location Map of Existing Blanchard to Lye Overflow Area

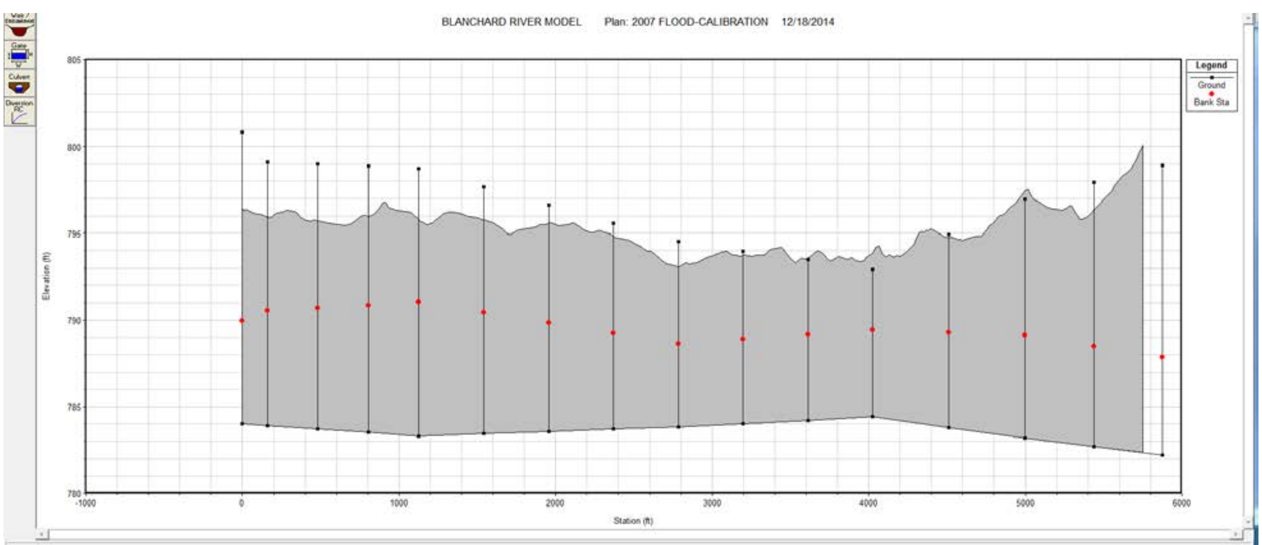

Figure 30. Township Road 240 Lateral Weir Profile Used in HEC-RAS to Simulate Overflow from the Blanchard River into Lye Creek

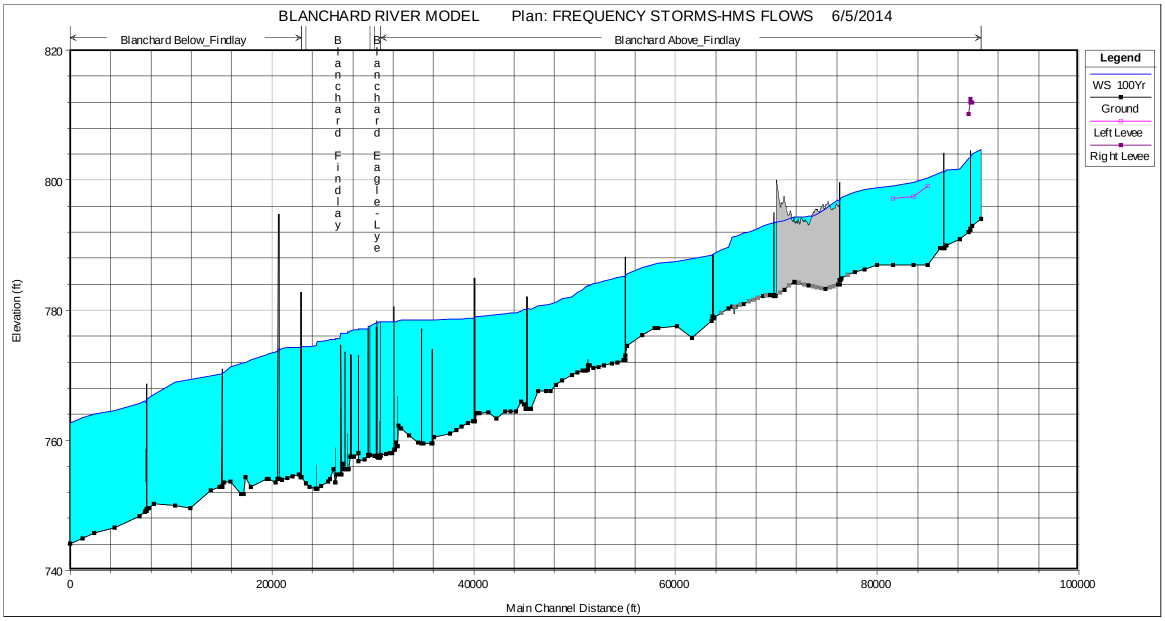

Figure 31. HEC-RAS Simulated 1% Annual Chance (100-Year) Water Surface Elevations along the Blanchard River in the Vicinity of Findlay

4.2.5 Proposed Condition Hydraulic Performance

The calibrated HEC-RAS model was modified to reflect alternative flood risk management plans and to analyze the hydraulic performance of those alternatives. The HEC-RAS model, for each alternative, coupled with the HEC-HMS model was used to simulate the hydraulic performance for each flood mitigation alternative. The HEC-RAS model output for each alternative was then used as input data for an economic benefits analysis in HEC-FDA.

Five flood mitigation alternatives were analyzed using the combined H&H models. The alternatives included:

- Alternative 1 – Without Project Condition or No Action Alternative
- Alternative 2 – 2% Annual Chance (50-Year) Event Diversion Channel with Blanchard-Lye Cutoff Levee
- Alternative 3 – 1% Annual Chance (100-Year) Event Diversion Channel with Blanchard-Lye Cutoff Levee
- Alternative 4 – 0.4% Annual Chance (250-Year) Event Diversion Channel with Blanchard-Lye Cutoff Levee
- Alternative 5 – 1% Annual Chance (100-Year) Event Diversion Channel without Blanchard-Lye Cutoff Levee

Diversion effects were simulated according to the flow reduction at the Eagle Creek diversion point.

Figure 32. Model Simulated 1% Annual Chance (100-Year) Flood Extent in the Vicinity of Findlay, OH

5. DESCRIPTION OF FLOOD RISK MITIGATION ALTERNATIVES

5.1 Alternative 1: Without Project Condition or No Action

This alternative reflects the current, or baseline condition. The purpose of including the no action alternative is to provide a consistent baseline for comparison against other alternatives, and to describe the flood impacts associated with not developing a flood risk management project.

5.2 Alternative 2: 2% Annual Chance (50-Year) Event Diversion Channel with Blanchard-Lye Cutoff Levee

A diversion channel is built to divert high flows from Eagle Creek to the Blanchard River, downstream of Findlay. The diversion channel alignment extends from Eagle Creek just downstream of County Road 45 to the Blanchard River downstream of Aurand Run. A gated flow control structure on Eagle Creek restricts flow in Eagle Creek to a maximum of the 50% annual chance (2-year return period) flow. Flows in excess of the 50% annual chance flow are directed into the diversion channel. For Alternative 2, the diversion channel is designed for the 2% annual chance (50-year) event. That is, the diversion channel is designed to handle the 2% annual chance (50-year) flow for Eagle Creek upstream of the diversion point, minus the 50% annual chance (2-year) flow which is allowed to continue in Eagle Creek, downstream of the diversion point.

Additionally, a levee is built to separate flood flows in the headwater of Blanchard River and Lye Creek. The levee alignment is consistent with the overflow weir location shown in Figure 29.

5.3 Alternative 3: 1% Annual Chance (100-Year) Event Diversion Channel with Blanchard-Lye Cutoff Levee

Same as Alternative 2, except the diversion channel is designed to convey the 1% annual chance (100-year) flow, minus the 50% annual chance (2-year) flow.

5.4 Alternative 4: 0.4% Annual Chance (250-Year) Event Diversion Channel with Blanchard-Lye Cutoff Levee

Same as Alternative 2, except the diversion channel is designed to convey the 0.4% annual chance (250-year) flow, minus the 50% annual chance (2-year) flow.

5.5 Alternative 5: 1% Annual Chance (100-Year) Event Diversion Channel without Blanchard-Lye Cutoff Levee

Same as Alternative 3, except without the Blanchard-Lye Cutoff Levee.

5.6 Alternative 10: 1% Annual Chance (100-Year) Event Diversion Channel with Eagle Creek at 100 cfs without Blanchard-Lye Cutoff Levee

Same as Alternative 5, except Eagle Creek, downstream of the diversion structure conveys 100 cfs.

6.0 ALTERNATIVES MODELING METHODOLOGY AND RESULTS

6.1 Modeling Methodology

The hydraulic performances of the alternatives were analyzed using the coupled H&H model. The hydrologic model HEC-HMS was used to compute frequency peak flows at various locations in the watershed, and these peak flows were then assigned in the HEC-RAS hydraulic model to estimate the WSELs. The hydraulic modeling efforts for the alternatives included modifying the channel geometry where necessary to incorporate the proposed changes. The diversion effect was simulated using peak flow deduction at the diversion point in Eagle Creek. Figure 33 shows the location of the proposed diversion structure and channel diverting flow from Eagle Creek to the Blanchard River downstream of Findlay.

The diversion structure consists of an inline culvert structure with gates in the headwater and a side spill weir on the left bank. For Alternatives 2 though 5, the diversion structure gates would be operated to ensure a maximum of bankfull flow (approximately the 50% annual chance, or 2-year return period flow) in Eagle Creek with the excess flow entering the diversion channel. For Alternative 10, the diversion structure gates would be operated to ensure a flow of just 100 cfs would continue down Eagle Creek during periods of anticipated flooding along the Blanchard; at all other times, Eagle Creek would be allowed to flow free up to a maximum of the 10-year event.

The 50% annual chance (2-year) return period flow maximum was initially identified as being necessary to maintain a healthy ecosystem in Eagle Creek downstream of the diversion structure. Eagle Creek would remain active during normal flow conditions and the diversion channel will be active only under flood conditions in excess of the 50% annual chance (2-year) flow on Eagle Creek. Additional study indicated Alternative 10 would provide a similar level of environmental protection relative to capping flows in Eagle Creek at the 2-year flow.

6.2 Comparison of Alternative Flows in Eagle Creek Downstream of the Diversion Structure

While Alternatives 2 through 5 propose flows in Eagle Creek downstream of the diversion structure be capped at the 2-year flow (1,230 cfs), Alternative 10 proposes flows in Eagle Creek be limited to 100 cfs during periods of anticipated flooding in the Blanchard. An analysis of these alternative flow approaches was conducted with respect to the potential impact on flow frequency distribution and sediment transport.

The analyses were conducted on the full period of record for flows on Eagle Creek. Data from the USGS streamgages on Eagle Creek and on the Blanchard at Findlay for the period

October 2007 to February 2015 (2,702 days) were obtained. The combined data were sorted such that flows in the Blanchard were arranged in descending order.

For days where Blanchard River flows were greater than 5,000 cfs (approximately the 5-year flow), actual Eagle Creek flows were replaced with 100 cfs. The Eagle Creek flow records, both actual and modified, were then sorted in ascending order and plotted (see Figure 34). Similarly, actual Eagle Creek flows were modified to reflect the approach of always capping Eagle Creek flows at the 2-year event (1,230 cfs) (i.e. the Alternatives 2 through5, or TSP flow rule) (see Figure 35). The flow distribution for the Alternative 10 flow rule is more consistent with that of actual flows.

Frequencies of bankfull flows were also compared. Table 14 shows the expected annual flow distribution for actual flows, the proposed Alternative 10 Eagle Creek flow rule, and for the TSP Eagle Creek flow rule, based on the 2,702 days of record. As can be seen from the table, there are more flows at bankfull (2-year event) and above for existing conditions and the TSP than for the proposed Alternative 10 flow rule. However, in the last 2,702 days (~7 ½ years), there have been considerably more bankfull flow or above events than would be expected (3.2/year vs. an expected 0.5/year). And under the Alternative 10 rule, there would have been 2.1/year. Section 7.0, below, discusses the observed impact of climate change on the region's hydrology. So, while the Alternative 10 flow rule is expected to reduce the frequency of flows at or above the 2-year flow somewhat, there may still be considerably more than would be expected regardless.

The potential impact of the Alternative 10 flow rule on sediment transport was also examined. Wolman and Miller (1960) established the concept of effective discharge of sediment. They discuss that while large storms transport huge quantities of sediment because sediment transport increases exponentially with applied stress (i.e. flow), smaller storms occur more frequently. By considering both the discharge/sediment transport and flow frequency relationships coincidentally, it becomes clear that bankfull discharge is the maximally effective discharge – i.e. bankfull flows both occur frequently and transport significant amounts of sediment. However, large storms still transport larger quantities of sediment. And the Alternative 10 flow rule allows for flows above bankfull, as long as flooding along the Blanchard is not anticipated.

Sediment rating curves relate sediment load as a function of stream discharge, and take the general form:

$$Q_s = \alpha Q^{\beta}$$

Where:

- Qs = sediment load (e.g. tons/day)
- Q = stream discharge (e.g. cfs)
- α , β = coefficient and exponent, respectively, determined empirically

Colby (1956) measured sediment discharge for a number of rivers, including the Sandusky River in Ohio. Sediment load in the Sandusky is dominated by fines, and was found to fit the equation:

$$Q_s = 0.00093Q^{1.74}$$

where Qs is in tons/day, and Q is in cfs.

Annual sediment load was then calculated using the sediment rating equation from Colby (1956), for each flow range. For each flow range and condition (existing, proposed Alternative 10, and TSP), the total sediment load was calculated as the product of sediment load times days/year in each flow range (see Table 15). Sediment transport for the proposed Alternative 10 flow rule is just 6% less than that for the TSP.

A sensitivity analysis, using sediment rating curve parameters established through measurements in other rivers (Colby, 1956), found the above result to be relatively insensitive to the parameter values of the sediment rating curve. Of the parameter sets for the five rivers studied in Colby (1956), four resulted in differences in the range -6% to +6%, while the fifth resulted in a difference of +50% (i.e. Alternative 10 flow rule generating 50% more sediment transport than the TSP flow rule). Thus, it appears reasonable to conclude that the sediment transport characteristic of the Alternative 10 approach is approximately equivalent to that of the TSP.

6.3 Results

The conceptual diagram of the diversion structure is shown in Figure 36. The proposed Eagle Creek diversion structure embankment would impound less than the 500 acre-foot impoundment threshold and therefore may not be subject to strict dam safety regulations due to its small footprint and storage volume. Figure 37 shows the inundation upstream of the Eagle Creek Structure, expected to occur under flood conditions. Figure 38 shows the modeled inundation area for the TSP for the 1% annual chance (100-year) flood event.

The Blanchard to Lye overflow cutoff levee would prevent flood waters from overflowing into Lye Creek from the Blanchard River, thus protecting low-lying areas on the downstream end of Lye Creek. A comparison of model results for the TSP versus existing conditions, however, indicate an area of 1,579 acres may be impacted by induced flooding for the 1%

annual chance (100-year) event. That is, an area of 1,579 acres would be expected to experience higher flood depths for that event. Model results indicate the increase in the peak flood depth varied significantly over the area, from less than 1 inch to as much as 4 feet, for the 1% event. Additionally, peak flows downstream of where the diversion channel re-enters the Blanchard, are expected to rise by approximately 250 cfs.

For each alternative, WSELs were simulated for the 50%, 20%, 10%, 4%, 2%, 1%, 0.4%, and 0.2% annual chance events (i.e. 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 250-year, and 500-year return periods). Tables 16 through 20 show simulated WSELs for the existing conditions (or baseline, or no action alternative) versus a proposed alternative for a few selected locations of the project area.

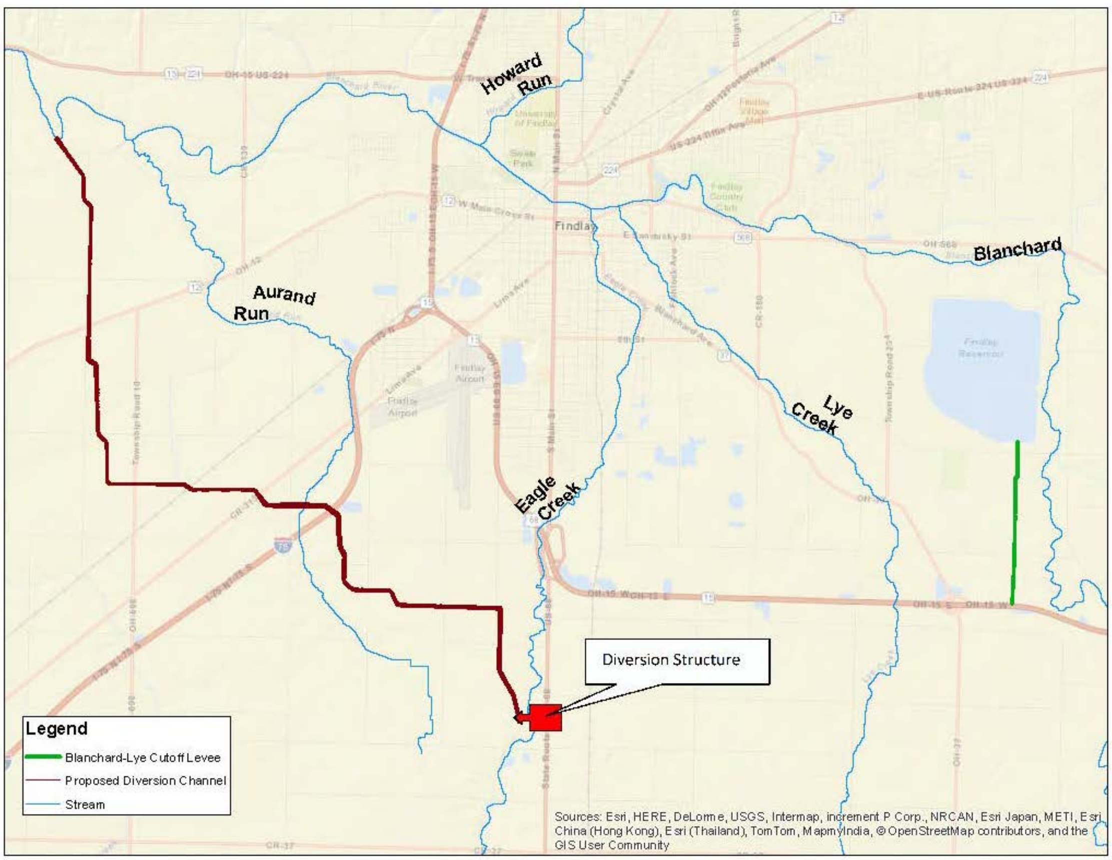

Figure 33. Proposed Diversion Structure and Channel from Eagle Creek to the Blanchard River

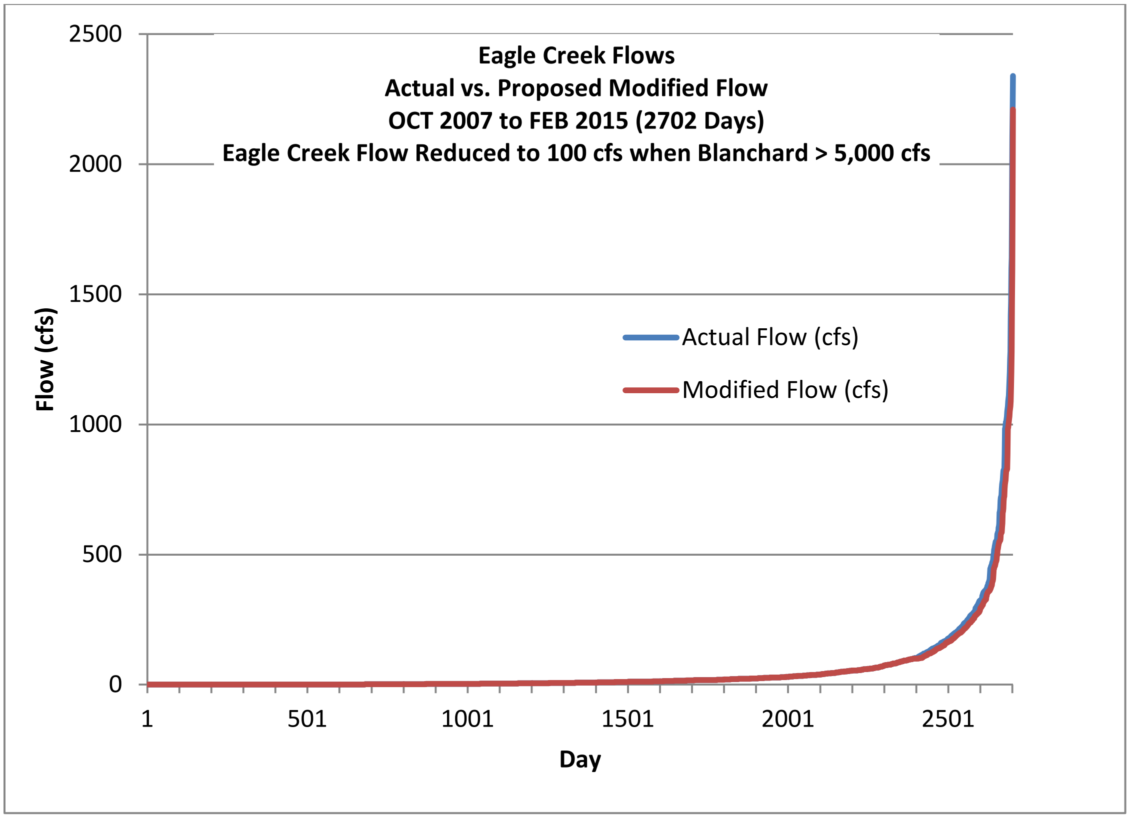

Figure 34. Ranking of Flows: Eagle Creek Alternative 10 Rule vs. Actual

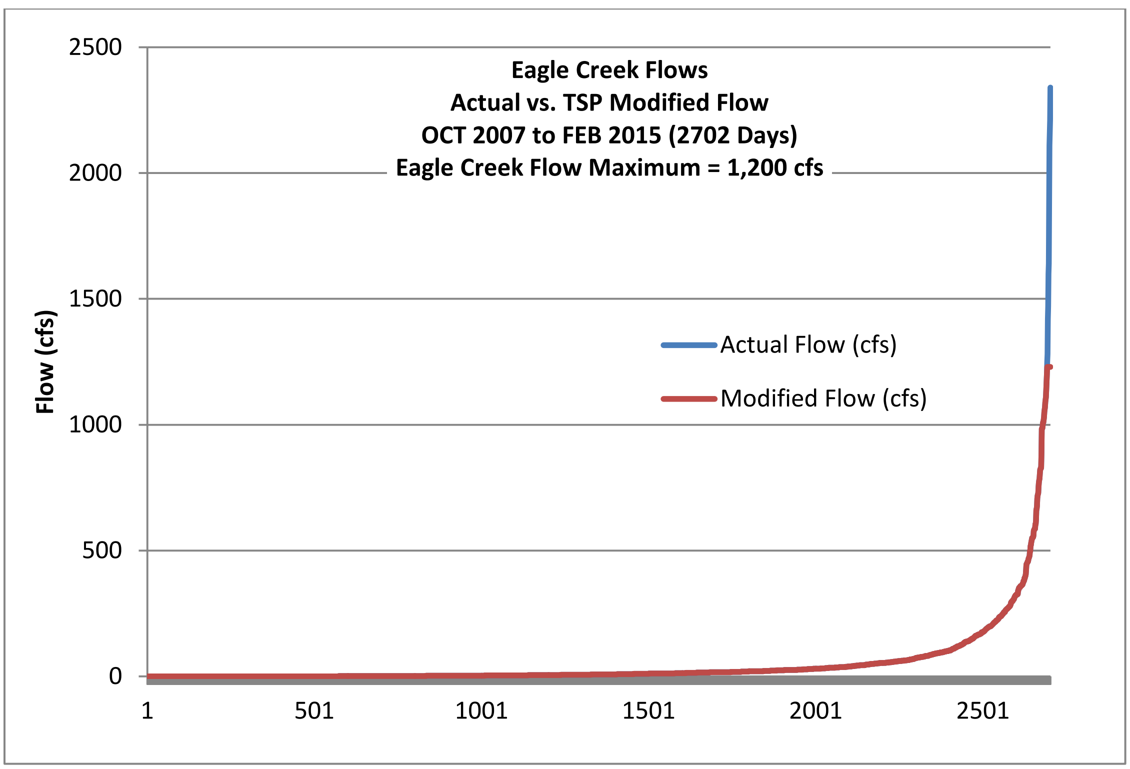

Figure 35. Ranking of Flows: Eagle Creek Alternative 10 Rule vs. TSP Rule

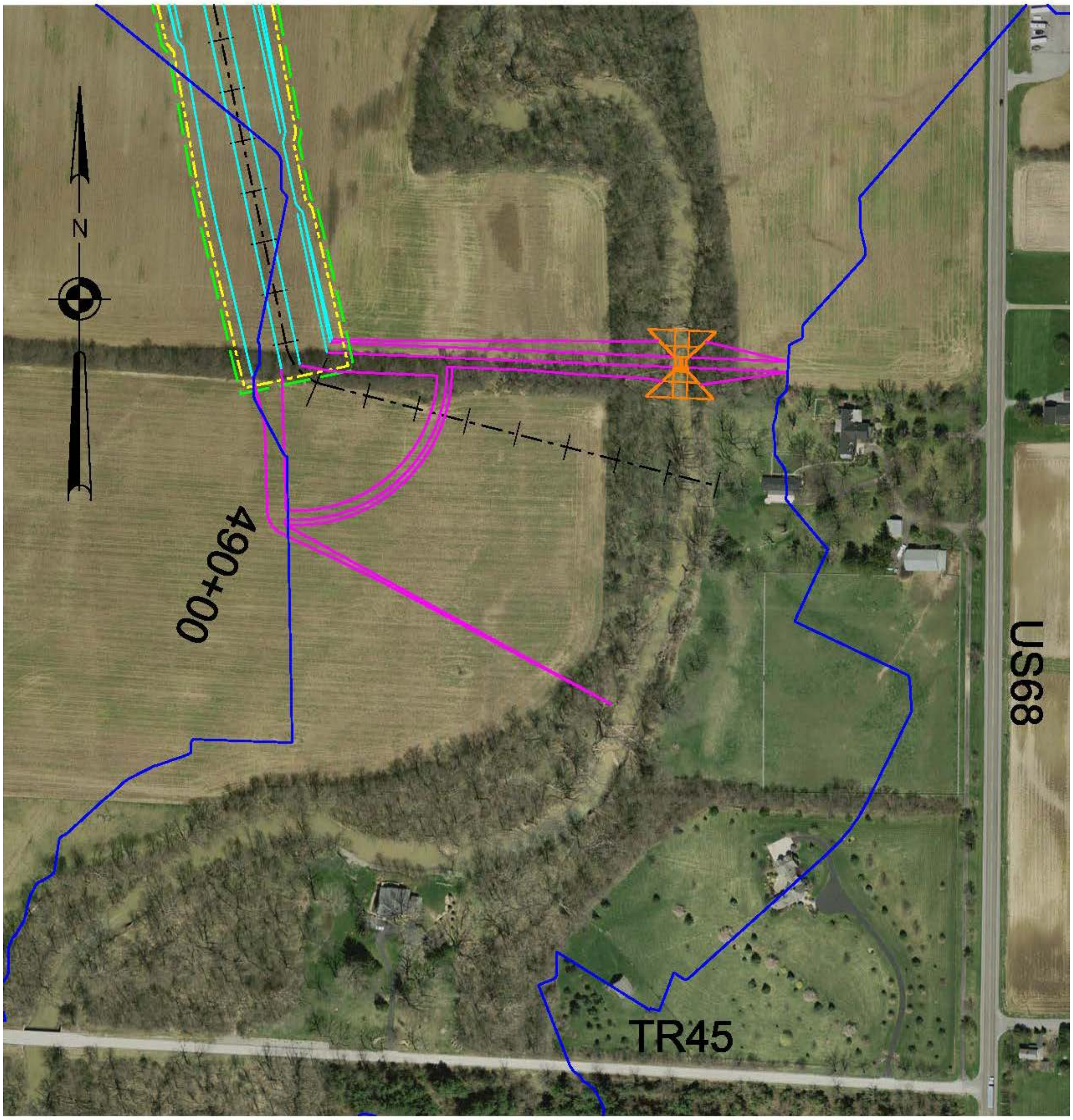

Figure 36. Conceptual Diagram of the Proposed Diversion Structure on Eagle Creek

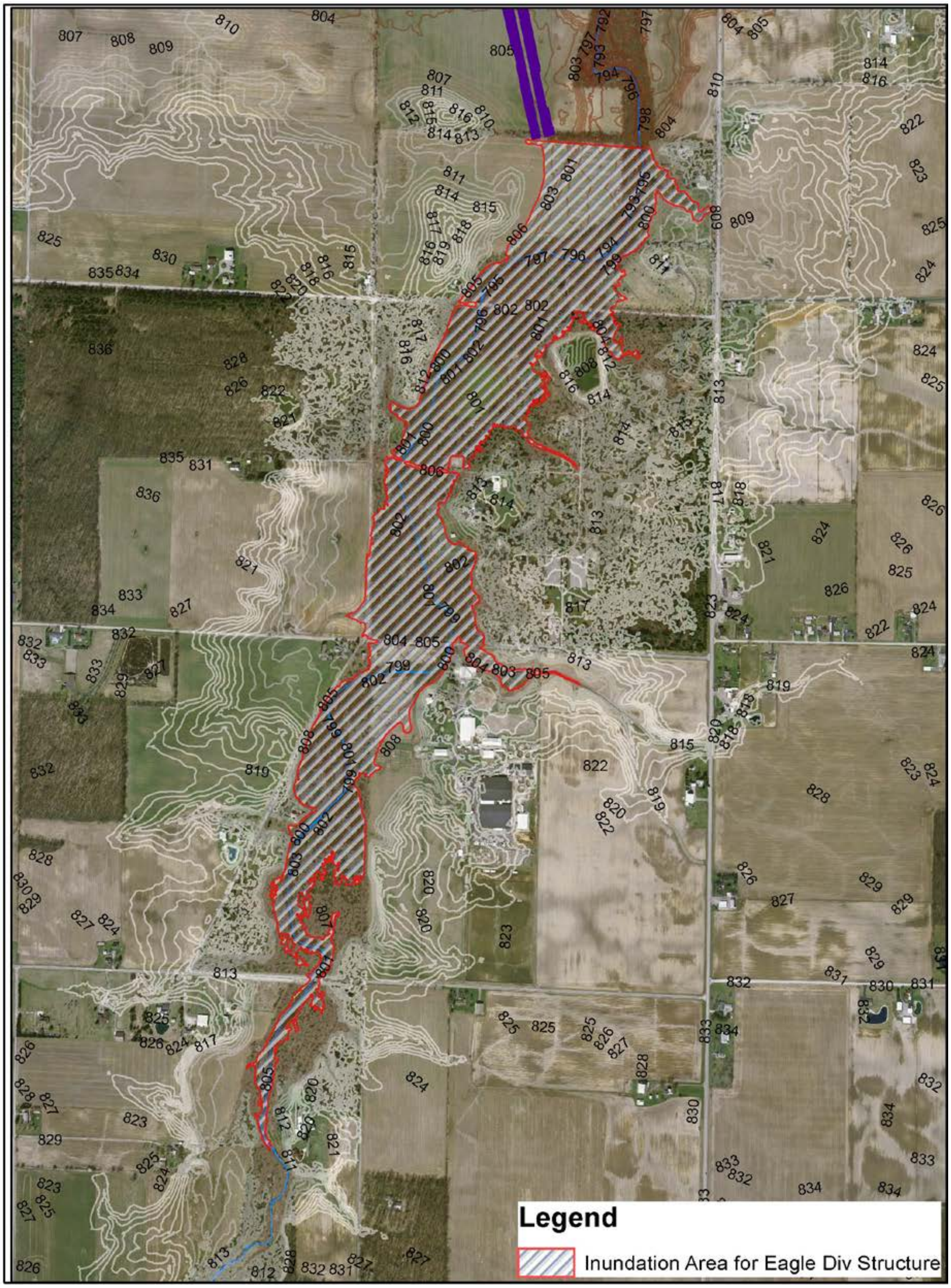

Figure 37. Inundation Area of the Proposed Diversion Structure on Eagle Creek under Flood Conditions

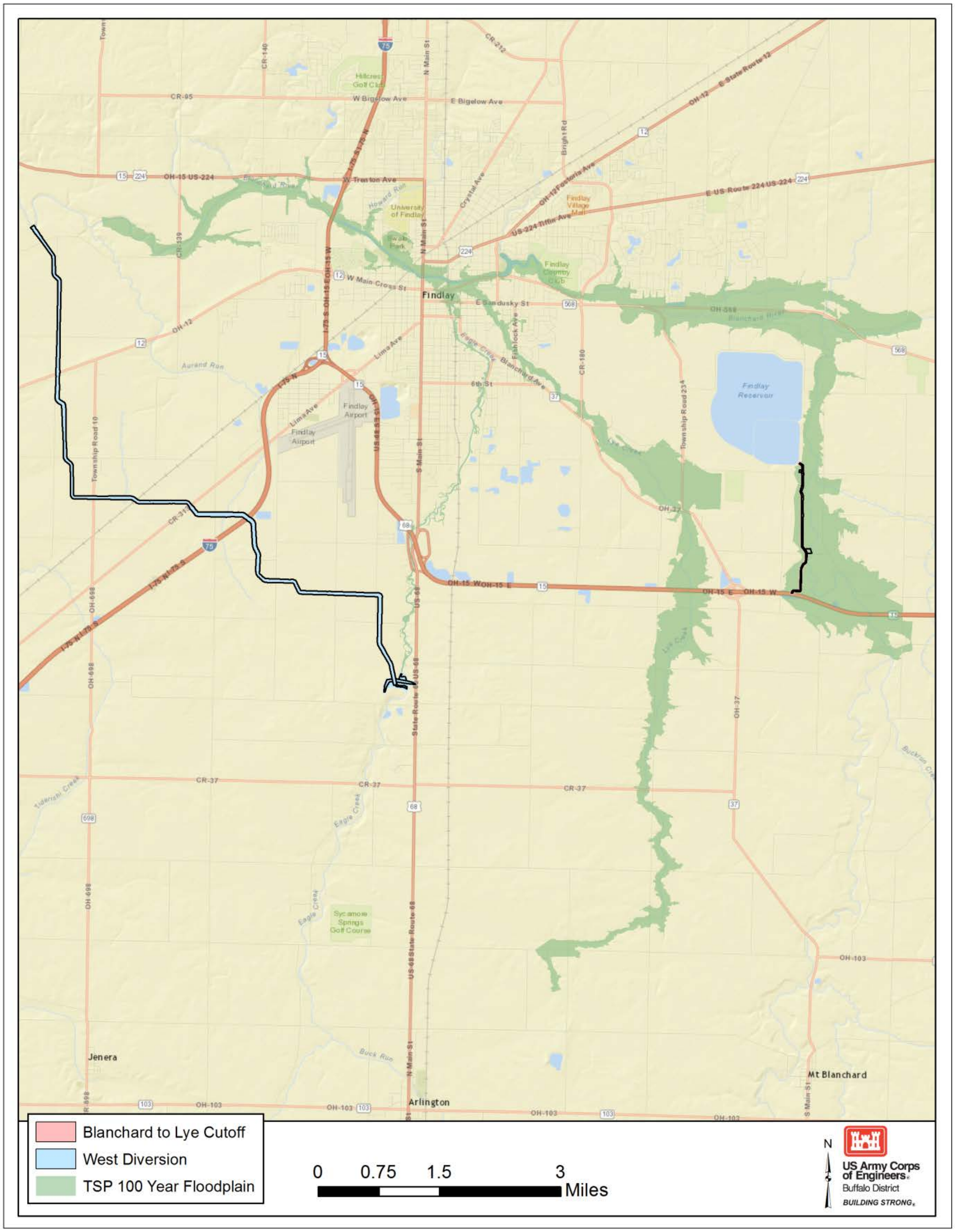

Figure 38. Model Simulated Inundation for the TSP for the 1% Annual Chance (100-Year) Flood Event

Table 14. Comparison of Expected Annual Flow Distributions: Existing, Proposed Alternative, and TSP

Flow Range (cfs)	Return Interval	Days/Year in Range		
		Existing	**Proposed***	**TSP**
0-20	1.5 d	243	243	243
20-50	1 wk	50	50	50
50-100	1.7 wk	30	30	30
100-200	2.9 wk	18	20	18
200-500	3.3 wk	16	16	16
500-1,000	2.4 mo	4.9	4.6	4.9
1,000-1,229	2 yr	1.9	1.4	3.2
1,229-1,872	5 yr	0.8	0.4	0.0
1,872-2,374	10 yr	0.5	0.3	0.0
	Totals:	**365**	**365**	**365**

* - Alternative 10 flow rule, with 5,000 cfs Blanchard River flow threshold

Table 15. Comparison of Expected Annual Sediment Load: Existing, Proposed Alternative, and TSP

	Sediment*	Annual Sediment Load (tons/yr)**		
Flow Range	(tons/day)	Existing	Proposed***	TSP
0-20	0	12	12	12
20-50	0	23	23	23
50-100	2	51	51	51
100-200	6	101	113	101
200-500	25	403	389	403
500-1,000	94	455	430	455
1,000-1,229	182	345	246	591
1,229-1,872	313	253	127	-
1,872-2,374	561	303	152	-
Totals:		***1,946***	***1,542***	***1,636***

* - Calculated using equation from Colby (1956), and midpoint of the flow range.
** - Calculated as product of sediment load and flow frequency from Table 14.
*** - Alternative 10 flow rule, with 5,000 cfs Blanchard River flow threshold

Table 16. Summary of Water Surface Elevations (WSELs) for Existing Conditions and Proposed Flood Mitigation Alternative 2

Frequency (Annual Chance/ Return Period)	Existing Condition WSEL				Proposed Improvement Condition (Alternative 2) WSEL			
	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)
50% 2-yr	766.47	768.30	770.63	770.34	766.84	768.58	770.83	770.56
20% 5-yr	768.55	770.79	771.96	772.91	768.62	770.66	771.82	772.54
10% 10-yr	770.08	772.71	773.80	773.92	769.63	771.92	773.13	772.75
4% 25-yr	771.75	774.64	775.80	775.91	770.85	773.41	774.69	774.22
2% 50-yr	772.81	775.78	776.98	776.92	771.65	774.37	775.71	775.2
1% 100-yr	773.88	776.85	778.28	778.26	772.7	775.62	777.02	776.5
0.4% 250-yr	775.08	777.80	779.31	779.22	774.13	777.24	778.71	778.23
0.2% 500-yr	776.15	778.52	779.86	779.78	775.1	778.39	779.82	779.39

Table 17. Summary of Water Surface Elevations (WSELs) for Existing Conditions and Proposed Flood Mitigation Alternative 3

Frequency (Annual Chance/ Return Period)	Existing Condition WSELs				Proposed Flood Mitigation Alternative 3 WSELs			
	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)
50% 2-yr	766.47	768.30	770.63	770.34	766.84	768.58	770.83	770.56
20% 5-yr	768.55	770.79	771.96	772.91	768.62	770.66	771.82	772.54
10% 10-yr	770.08	772.71	773.80	773.92	769.63	771.92	773.13	772.75
4% 25-yr	771.75	774.64	775.80	775.91	770.85	773.41	774.69	774.22
2% 50-yr	772.81	775.78	776.98	776.92	771.65	774.37	775.71	775.2
1% 100-yr	773.88	776.85	778.28	778.26	772.44	775.35	776.76	776.17
0.4% 250-yr	775.08	777.80	779.31	779.22	773.83	776.7	778.23	777.68
0.2% 500-yr	776.15	778.52	779.86	779.78	774.93	778.25	779.72	779.21

Table 18. Summary of Water Surface Elevations (WSELs) for Existing Conditions and Proposed Flood Mitigation Alternative 4

Frequency (Annual Chance/ Return Period)	Existing Condition WSELs				Proposed Flood Mitigation Alternative 4 WSELs			
	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)
50% 2-yr	766.47	768.30	770.63	770.34	766.84	768.58	770.83	770.56
20% 5-yr	768.55	770.79	771.96	772.91	768.62	770.66	771.82	772.54
10% 10-yr	770.08	772.71	773.80	773.92	769.63	771.92	773.13	772.75
4% 25-yr	771.75	774.64	775.80	775.91	770.85	773.41	774.69	774.22
2% 50-yr	772.81	775.78	776.98	776.92	771.65	774.37	775.71	775.20
1% 100-yr	773.88	776.85	778.28	778.26	772.44	775.35	776.76	776.17
0.4% 250-yr	775.08	777.80	779.31	779.22	773.65	776.49	777.96	777.39
0.2% 500-yr	776.15	778.52	779.86	779.78	774.79	778.16	779.64	779.07

Table 19. Summary of Water Surface Elevations (WSELs) for Existing Conditions and Proposed Flood Mitigation Alternative 5

Frequency (Annual Chance/ Return Period)	Existing Condition WSELs				Proposed Flood Mitigation Alternative 5 WSELs			
	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)
50% 2-yr	766.47	768.30	770.63	770.34	766.44	767.92	770.23	770.10
20% 5-yr	768.55	770.79	771.96	772.91	768.35	770.16	772.51	772.11
10% 10-yr	770.08	772.71	773.80	773.92	769.40	771.39	772.58	772.32
4% 25-yr	771.75	774.64	775.80	775.91	770.63	772.87	774.11	773.78
2% 50-yr	772.81	775.78	776.98	776.92	771.46	773.94	775.17	774.83
1% 100-yr	773.88	776.85	778.28	778.26	772.27	774.96	776.20	775.83
0.4% 250-yr	775.08	777.80	779.31	779.22	773.69	776.39	777.65	777.41
0.2% 500-yr	776.15	778.52	779.86	779.78	774.96	777.80	779.39	778.97

Table 20. Summary of Water Surface Elevations (WSELs) for Existing Conditions and Proposed Flood Mitigation Alternative 10

Frequency (Annual Chance/ Return Period)	Existing Condition WSELs				Proposed Flood Mitigation Alternative 10 WSELs			
	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)	I-75 Bridge (Blanchard River XS 288785)	Main St. (OH-12) Bridge (Blanchard River XS 295930)	Osborne Ave Bridge (Blanchard River XS 300910)	E. Sandusky St. (Eagle Creek XS 1554)
50% 2-yr	766.47	768.30	770.63	770.34	765.16	766.52	768.95	767.98
20% 5-yr	768.55	770.79	771.96	772.91	767.22	768.83	771.29	770.43
10% 10-yr	770.08	772.71	773.80	773.92	768.41	770.23	772.69	771.93
4% 25-yr	771.75	774.64	775.80	775.91	769.74	771.87	773.22	772.58
2% 50-yr	772.81	775.78	776.98	776.92	770.65	772.90	774.31	773.68
1% 100-yr	773.88	776.85	778.28	778.26	771.74	774.24	775.66	775.03
0.4% 250-yr	775.08	777.80	779.31	779.22	773.08	775.80	777.26	776.69
0.2% 500-yr	776.15	778.52	779.86	779.78	774.42	777.29	779.04	778.45

7. CLIMATE CHANGE

7.1 Phase I. Qualitative Assessment

The flood risk management study is intended to reduce damage associated with flood events in northwest Ohio in the vicinity of the Blanchard River. The possibility of climate change increasing the magnitude or frequency of flood flows needs to be considered for adverse effects to the project.

7.2 Phase II. Identification of Climate Threats and Impacts

7.2.1 Analysis of the Observed Record

Daily flows from the Blanchard River near Findlay gage (USGS gage 04189000) were obtained from the entire period of record, 10 October 1923 through 30 September 2014. Linear regression was performed on the annual maximum daily discharges (Figure 39) as well as on the annual maximum three-day average discharges (Figure 40). Simple linear regression with test statistics was performed using the method of least squared errors in Microsoft Excel's "Analysis Toolpack" to determine statistical significance of the slope. Only full years of data in the period of record were used for the regression; 1923, 1936-1940, and 2014 were excluded. Both analyses resulted in a relatively small but statistically significant trend with a 95% confidence towards larger annual maximum daily discharges and larger annual maximum three-day average discharges.

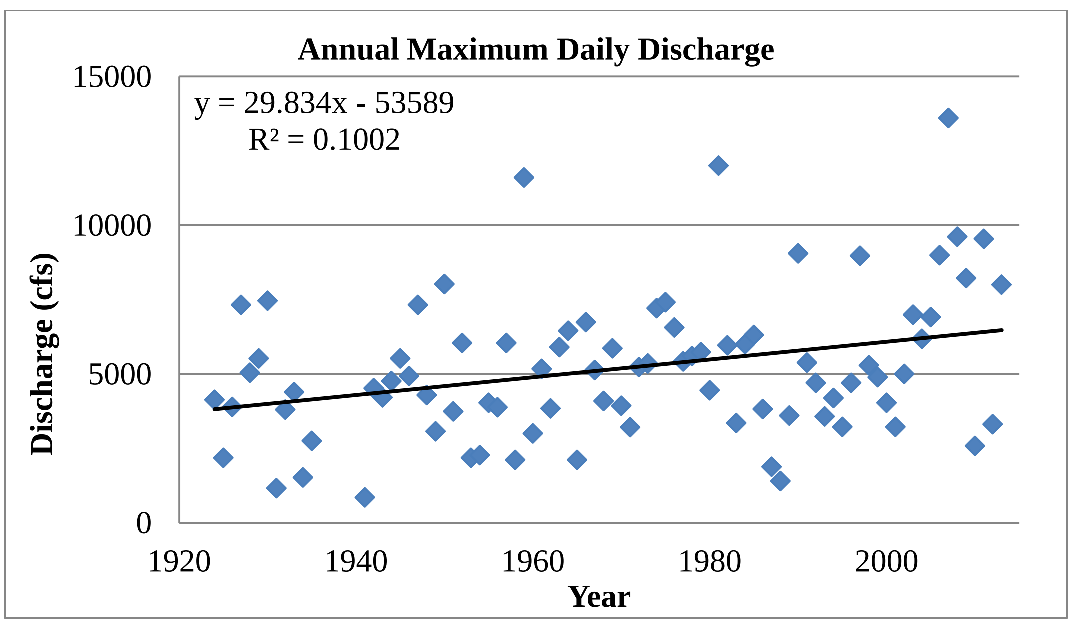

Figure 39. First-Order Trend Detection for Observed Annual Maximum Daily Flows in the Blanchard River near Findlay. A positive slope is determined to be statistically significant at the 95% confidence level.

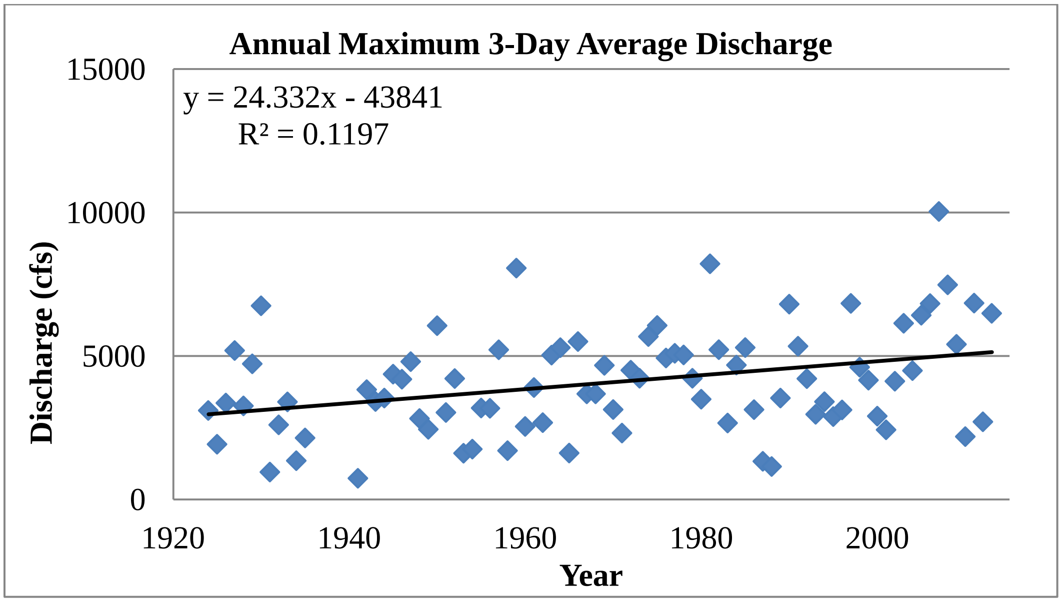

Figure 40. First-Order Trend Detection on Observed Annual Three-Day Maximum Daily Flows in the Blanchard River near Findlay. A positive slope is determined to be statistically significant at the 95% confidence level.

7.2.2 Analysis of the Projected Future Condition

The NOAA National Environmental Satellite, Data and Information Service (NESDIS) released a report in January 2013 that assessed climate trends and scenarios into the next 50–100 years for the Midwest region (Kunkel et al. 2013). The report indicates that over the period of hydroclimatological record for northwest Ohio, both temperature and precipitation have trended above normal, especially over the last 40 years. To account for climate change, the forecast of future meteorological conditions in the region considers the past temperature and precipitation records, as well as the modeled future conditions in the area through 2070. According to the NESDIS report, a warming trend of about 3–6°F and a precipitation trend toward slightly wetter conditions can be expected over the next 50 years, although these estimates have significant uncertainty. Numerous reputable and peer-reviewed climate change syntheses, including Kunkel et al. (2013), suggest that a warming climate can cause an increase in extreme weather events with the risk of heavy precipitation and flooding. However, Small (2006) has shown that the increased precipitation in some areas of the Midwest is occurring during the fall causing increased low flows while high flows do not increase. The USACE screening-level watershed vulnerability assessment for HUC 0410 showed that this watershed is among the 20% most vulnerable watersheds with regard to flood risk reduction and considering wet climate change scenarios. This vulnerability is primarily due to the cumulative and local flood magnification factor (FMF, Vogel et al. 2011). The cumulative and local FMF computed for the watershed (as of December 2014) are greater than 1.0 for wet and dry future conditions; indicating that flood magnitudes are expected to increase in the future.

Statistical analysis of changes in floods for both the observed record and the projected future were based on bias-corrected and spatially downscaled data (Data Archive 2014) from simulations developed for the Coupled Model Intercomparison Project Phase 5 (CMIP5) data, with hydrologic response simulated by the Variable Infiltration Capacity (VIC) model (Liang et al. 1994).

- The linear regression analysis for the 97 simulations during the time period from 1950 through 1999 indicates no statistically significant trend for runoff volume (Figure 41). Note that this is a review of modeled condition as opposed to actual measurements, which are shown in Figure 39.
- The linear regression analysis for the projected 2000 to 2099 time period showed a statistically significant trend to the 95% level for run off volume (Figure 42).

7.3 Conclusion

The observed runoff data for the Blanchard River near Findlay shows a statistically significant positive trend in the period of record, which agrees with the literature which predicts increased runoff due to the increase in extreme weather events in the future. However, it should be noted that land use changes over the period of record were ignored which could explain part of the increase in runoff. The USACE screening-level watershed vulnerability assessment indicates that the FMF is greater than 1.0 for the future wet and dry scenarios. The linear regression of the projected future conditions from CMIP5 data showed a statistically significant upward trend over the next 50 years. Based on this assessment, all literature and published data indicates increased runoff in the future.

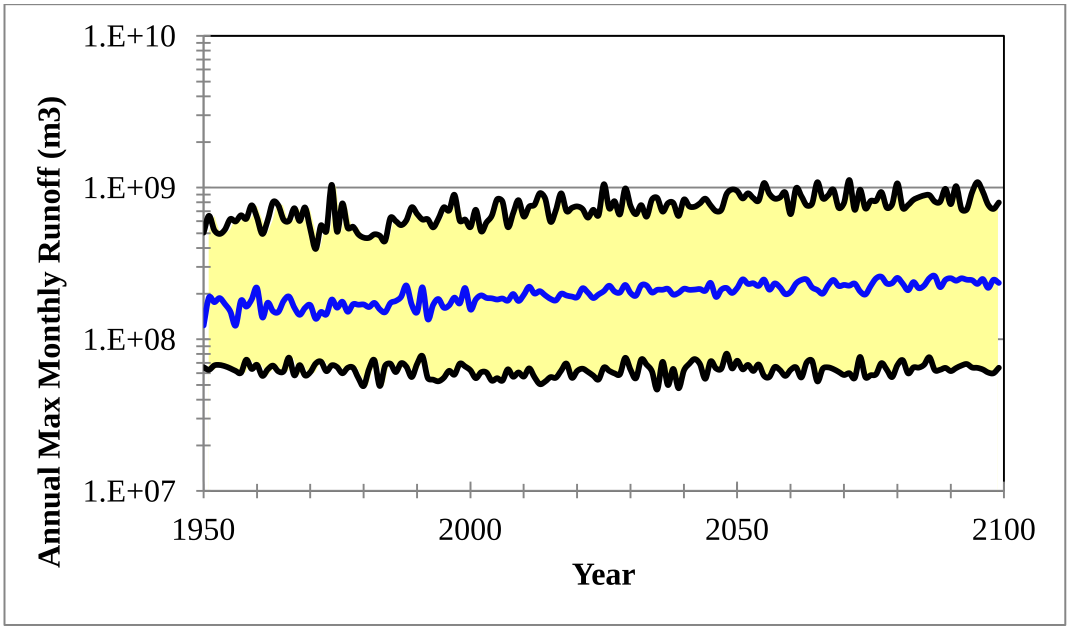

Figure 41. Projections of Climate-Changed Hydrology for HUC 4 0410. The mean of 97 projections of annual maximum monthly runoff volume is in blue and the range of those 97 projections is in yellow.

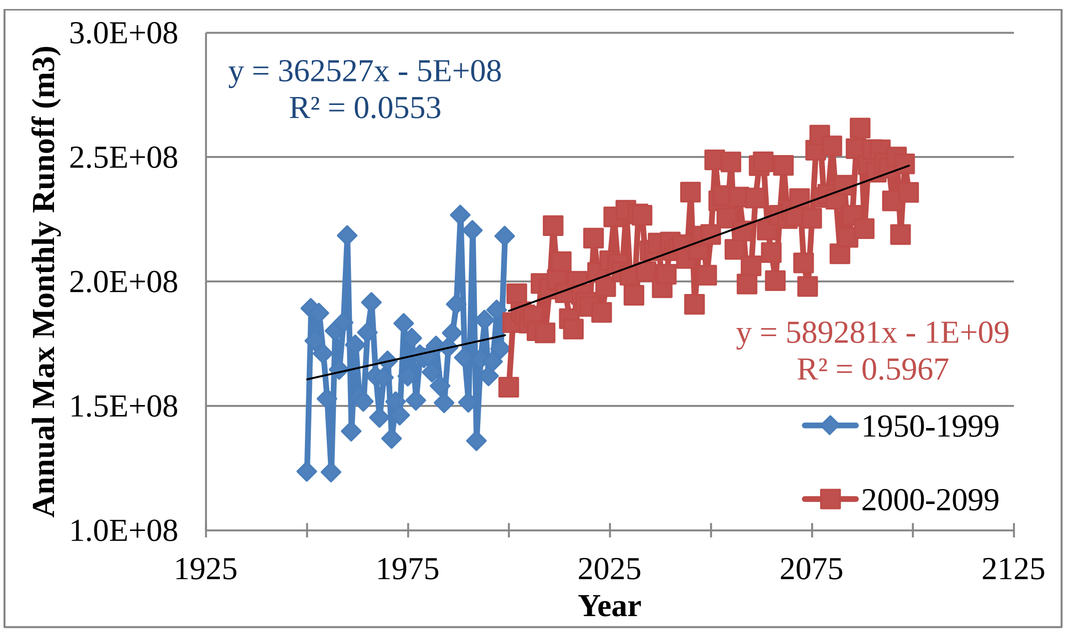

Figure 42. Statistical Analysis of the Mean of the Annual Maximum Monthly Runoff Volume Projections. The 1950–1999 period has no statistically significant trend, but the trend for 2000–2100 is statistically significant at the 95% confidence level.

8. SUMMARY

The Blanchard River experiences frequent and severe flooding events. A combination of hydrologic and hydraulic models was developed to assist planners and engineers in developing engineering solutions to mitigate flood risk. The coupled hydrologic and hydraulic models were used to assess the extent and severity of flooding under various recurrence interval storms. The hydrologic model was calibrated to observed data and found to provide a good match to a variety of high flow events. The hydraulic model was calibrated to the August 2007 record flood event along the Blanchard River and provides a good fit to measured high water elevations.

Peak flow and stage are important because flood impacts are related to the maximum flood stage. Mitigating peak flows or stage was a key goal in deriving the solution. The river stage provides an estimate of the extent of flooding within the watershed and how many structures, and related damages, are impacted by flood events. Expected peak inflows and desired outflows are required to design properly functioning flood risk management structures.

Five flood mitigation alternatives were simulated using H&H models. These alternatives included a diversion channel of various capacities, designed to divert flow from Eagle Creek to the Blanchard River at a point downstream of the city of Findlay. The total watershed area of Eagle Creek at its junction with the Blanchard River is about 328 square miles. The area of the Eagle Creek watershed, upstream of the diversion point, is about 43 square miles. Thus, all alternatives considered in this analysis will leave flows from about 285 square miles of the Eagle Creek watershed unmitigated and, given sufficient precipitation, could still result in flooding in Findlay.

In addition, this analysis was conducted using a uniform rainfall rate over the whole of the Blanchard River basin, a rainfall pattern not typically expected to occur. Due to this approach, the benefits calculated in this analysis will tend to over-estimate actual benefits. The spatial extent of actual rainfall events will dictate the overall benefit of flood reduction from this a partial subbasin diversion. The uncertainly of expected rainfall distribution across the Blanchard could not be adequately quantified using the modeling techniques in this analysis. As a result, it is difficult to more accurately quantify the prospective benefits from these alternatives, reasonably.

Alternative 3, i.e. 1% annual chance (100-year) diversion channel and a Blanchard-Lye cutoff levee) was ultimately recommended as the Tentatively Selected Plan (TSP). This alternative includes a diversion channel with a flow capacity equivalent to the 1% annual chance (100-year) peak flow minus the maximum controlled 50% annual chance (2-year) peak flow in Eagle Creek. This alternative results in the highest net benefits in terms of reduced flood damages in the project area for the alternative analyzed.

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